THE TORREY CANYON

1. Introduction

1. Pollution of our coastline by oil, mainly by solid or semi-solid tarry deposits which adhere to skin and clothing, has long been a menace and a nuisance. Some of it is due to the discharge of crude or fuel oil at sea as a result of accident. Most is caused by the deliberate clearing of the more viscous oil-residues from the cargo compartments of tankers. It is now estimated that, world wide, about 500,000 tons of oil is spilt in this way each year, of which about one-fifth is released near British waters. Both oil and oil residues float on the surface of the sea, the former tending to spread widely as a thin opalescent film. Depending on the chemical and physical nature of the spilled material, the place of discharge, the tide, currents and winds, and the amount destroyed by natural action, it will be carried to the shore either as a free-flowing liquid, a viscous oil or in the more familiar form of tarry deposits.

2. Pollution reached serious proportions after the second world war as the volume of tanker traffic round our shores increased (it is now thirty times more than it was in 1938). In 1952 the Minister of Transport therefore appointed a Committee to consider the problem. The Committee was mainly concerned with pollution caused by the clearing of oil-residues from tankers and from the fuel tanks of other oil-driven vessels, and its report (Prevention of Pollution of the Sea by Oil) recommended that the discharge of such residues at sea should be prohibited or kept to a minimum over a wide area, including the whole of the North Sea, the Bay of Biscay and an area 650 miles wide stretching out into mid-Atlantic.

3. As a follow-up Her Majesty's Government convened a conference in 1954 which resulted in the signing of an International Convention designed to prevent the discharge of persistent (i.e. non-volatile) oils at sea. The Convention was later strengthened by amendments passed at a further International Conference in 1962, convened by the Inter-Governmental Maritime Consultative Organisation (IMCO), which adopted many of the recommendations suggested by the Ministry of Transport Committee as outlined in a Board of Trade manual (The Avoidance of Pollution of the Sea by Oil) issued in 1957. Discharge of oil-residues was to be permitted only at ports and, to this end, several British ports in the last few years have installed adequate cleaning facilities for removing oil sludge from tankers. The Convention also set a limit to the amount of oil which may be discharged at sea in prohibited zones, and made the owner or master liable to prosecution by the Government of the country where the ship was registered. The provisions of the Convention and its amendments were given legal effect for British ships under the Oil in Navigable Waters Acts of 1955 and 1963.

4. In July 1960, the Co-ordinating Advisory Committee on Oil Pollution of the Sea approached the then Minister for Science for help in deciding the best ways to deal with oil pollution of the foreshores of coastal resorts. It was agreed that the Warren Spring Laboratory of the Department of Scientific and Industrial Research (now the Ministry of Technology) should undertake this task. Their report on the Removal of Oil from Beaches was issued in April 1962. The Laboratory extended its investigations to the treatment and disposal of floating oil at sea, and prepared a report for IMCO on this subject in April 1963.

5. The method recommended in the first report of the Warren Spring Laboratory for the removal of liquid oil pollution from beaches was to treat the contaminated area with a solution of an emulsifier (detergent) dissolved in a hydrocarbon solvent (such as coal tar naphtha) in the proportion of one to ten, and applied in an amount of about one-quarter to one-half of the volume of oil to be removed. It was emphasised that this treatment must be followed by extensive hosing with fresh or sea water, and that the operation should preferably be carried out just before the approach of the incoming tide. This operation can be compared with the removal of oil or grease from one's hands. A detergent such as soap alone is of little use. In order to wash the oil away, a relatively stable oil in water emulsion must first be formed. This is done by wetting one's soaped hands and then rubbing them together. The resulting froth contains the oil as very fine droplets which are prevented from coalescing by a coating of emulsifier. The emulsion can then be washed away with water.

6. The Warren Spring Report stressed the fact that lumps of tarry material cannot be removed by this method since the emulsifier runs off the material without penetrating it. It was also pointed out that all effective detergents are toxic to marine and intertidal life, expecially shellfish. Other methods of removal of oil from beaches (mechanical, burning or 'cloaking' the oil with absorbent powder) were investigated but, except for the development of a mechanical device consisting of toothed discs for removing solid tar deposits from sandy beaches, were not considered practicable with the type of pollution that was usually encountered.

7. For the dispersion of oil on the surface of the sea the Laboratory again recommended that the most effective treatment was to apply emulsifier-solvent mixtures, followed in this case by thorough agitation of the water. For oil spilt in docks or harbours where detergents might be troublesome, the Laboratory suggested that efforts should be made to contain it with booms, and to remove it either by sucking or skimming, or to absorb or immobilise it with floating scavenging materials (e.g. straw, which absorbs the oil on its surface, or a fibrous plastic, which can be coated as cobweb-like threads on to the oil by spraying the patch with the plastic dissolved in a solvent). In both cases the floating mat of oil and scavenger can be gathered mechanically from the surface with relative ease. The report pointed out, however, that the mechanical (e.g. sucking) and scavenging methods then available, and in use in some harbours, were not suitable for treatment of oil on the open sea. The Laboratory did not recommend the use of high density powdered solids (e.g. sand, crushed clinker) which could be distributed over a patch of oil and to which the oil then adheres and sinks to the bottom, because it was found that the oil could be released from the sunken mass by agitation, even after several months under water.

Furthermore, there was the objection that the sunken oil mass could foul fishing gear and pollute beds of oysters and other shellfish.

8. In general, action based on these recommendations has proved adequate up to now. Excluding the *Torrey Canyon*, nine accidents have occurred in the last five years which could have led to gross pollution of British coasts. Six of them involved tankers. Sixteen other instances of accidental discharges of large amounts of oil were observed but, in the majority of these, pollution of the coastline was minimal, and the oil was dispersed by the use of emulsifiers. Between 40 and 50 prosecutions have been undertaken every year under the Acts mentioned earlier (paragraph 3), mainly by Harbour Authorities, for oil-pollution offences.

9. The total amount of oil estimated to have escaped as a result of the nine major accidents mentioned above was probably no more than 6,000 to 7,000 tons. The largest single quantity was 2,600 tons which escaped into the sea in March 1965 when the Liberian tanker *Otto N. Miller* collided with the Norwegian vessel *Nora* 10 miles south of Beachy Head. This oil was dispersed with an emulsifier, and there was little shore pollution. A very bad case of coastline pollution, at Wittering and Selsey in Sussex in January 1967, was by oil from a source which was never traced. Some ten miles of coastline were affected, and clearance is estimated to have cost £10,000. In January 1967, extensive pollution in Milford Haven harbour was caused by the discharge of only 250 tons of crude oil by the Liberian tanker *Chryssi P. Goulandris.*

10. The *Torrey Canyon* disaster has put the problem into a completely different perspective. It has revealed the enormous scale of the threat posed by the risk of accidents, especially to larger tankers. World oil production is now approaching 1,800 million tons per year and forms over one-half of all tonnage carried by sea. About 450 million tons of oil is at present imported into Europe each year, most of it passing through our waters. Large tankers are more economical than smaller ships because of their lower capital and operating costs per ton of oil carried. Unit transport costs for tankers of 100,000 dead weight tons (dwt), for example, are less than half of those for ships of 20,000 dwt. As a result, whereas in 1956 there were only 3 tankers with a capacity of over 30,000 dwt, 405 of the 781 tankers above 1,000 dwt commissioned in the five years 1961-65 were above this size, and had an average capacity of 40,000 dwt. Half of the new tanker tonnage being built at the end of 1966 was in ships over 150,000 dwt. Assuming this trend continues, it is estimated that the 1,100 million tons or more of crude oil which will be carried by sea by 1970, will be transported in tankers whose average size will be between 60,000 to 70,000 dwt, with some giant tankers larger than 250,000 dwt.

11. It follows that although accidents involving tankers can be expected to become less frequent as increasing size diminishes the number of ships operating, each accident will present a potentially more serious risk of pollution than the majority of those which have so far occurred. The fact that tankers, because of the way they are built, and because of the comparative ease with which their cargoes can be handled, are more easily salvable after stranding or collision than are other types of merchant vessel, provides little comfort, and no reason at all for complacency. The risk of accident is a very real one. In the three years preceding the wreck of the *Torrey Canyon*, 91 tankers were stranded in

various parts of the world, while 238 were involved in collisions either with tankers or other vessels. Over the world at large, tankers have thus been involved in potentially serious accidents on an average about twice a week for the past three years. Sixteen of the 329 ships which were concerned became total losses; in nine of the collisions fires broke out in one or both ships; and in 39 cases cargo spillage or leakage occurred.

12. The sea lanes round our coasts are the busiest in the world. The Western Approaches and the English Channel are the routes to the majority of the oil refineries of North West Europe, including those of the British Isles. It is thus reasonable to assume that the majority of tanker accidents which occur will occur in these seaways. Indeed, an analysis of past records suggest that on average about one in ten of all accidents at sea occurs in these waters each year. Bearing in mind the expected increase in the amount of oil imported into Europe and in the size of tankers (paragraph 10), there is a very real possibility, whatever precautions may be taken, that another incident involving a tanker of over 30,000 dwt will occur in the next ten years or so around our coasts. In addition, minor accidents, involving spillage of sufficient quantities of oil to seriously pollute some stretches of our coastline, can be expected to continue at the present rate of three or four times a year.

13. We have learnt a great deal from the *Torrey Canyon* disaster. The purpose of this report is to outline some of the lessons and to indicate the further enquiries which should be undertaken in order to improve the effectiveness of the measures that could be taken to obviate or counteract the consequences of similar disasters in the future.

2. The Course of Events

14. At 08.50 hours on Saturday, 18th March, 1967, the *SS Torrey Canyon* ran aground on the Seven Stones rocks (50° 02.5′N, 06° 07.5′W), approximately 16 miles west of Lands End, while on passage from the Persian Gulf to Milford Haven. At the time of grounding she was steering a northerly course at 16 knots in broad daylight. She was carrying 119,000 tons of Kuwait crude oil.

15. The *Torrey Canyon* struck the west side of the Pollard Rock and her momentum carried her forward so that she suffered bottom damage over at least half her length. An attempt was immediately made to regain buoyancy by jettisoning oil. This was continued until the pumps failed, following the closing down of the ship's boilers due to flooding, about 12 hours after the ship hit the rock. In the forward part of the ship, immediately aft of the forepeak, were five deep tanks which contained fuel oil. Aft of these fuel tanks were 18 cargo tanks, 16 of which contained oil. (No. 3 port and starboard tanks were being used as clean ballast tanks). Several of these tanks were breached and quantities of crude oil escaped into the sea. It is estimated that in the first few hours some 30,000 tons of cargo and fuel oil were lost in addition to the oil which was jettisoned.

16. Within two hours a Royal Navy helicopter was over the ship. It immediately became clear that oil pollution was on a scale which had no precedent anywhere. At about mid-day, the Dutch salvage tug *Utrecht* of the Bureau Wijsmuller arrived, followed later on the same day by three further tugs, to help in a salvage operation which it was hoped would be successful. In the afternoon, two ships of the Royal Navy began to spray the edges of the ever-growing oil slick with detergent, the only 'drill' which was either possible or sensible in the circumstances.

17. From the moment it was informed about what had happened, the Maritime Headquarters at Plymouth realised the serious implications of the disaster. On the afternoon of Sunday, 19th March, the Parliamentary Under-Secretary of State for Defence for the Royal Navy went to Plymouth to co-ordinate service and civilian efforts to combat pollution and to provide Ministerial authority for exceptional financial expenditure. By Monday, 20th March, a larger fleet of ships, both of the Royal Navy and on charter, was spraying detergent; intensive air reconnaissance of the movement of the oil slicks was being carried out and many discussions between salvage experts, agents of the owners, the Services and Local Authorities had been held.

18. When they went on board on the afternoon of Saturday, 18th March, the Dutch salvage team estimated that the *Torrey Canyon* was aground over three quarters of her length. On Monday, 20th March, they were joined by the Chief Salvage Officer of the Navy Department and by agents of the United States owners. On the advice of all the salvage experts, including the Chief Salvage Officer of the Navy Department, it was decided that there was a reasonable chance of salvaging the ship, provided the weather stayed fair, the ship remained unbroken, and power was available on board from auxiliary sources.

Apart from the question of salvage, this operation, if successful, would have prevented further pollution of the sea and coastline by the large quantity of oil it was estimated was still on board.

19. The Navy Department ferried salvage personnel and provided all possible assistance, including a hydrographical survey of the reef round the ship and heavy lifts of equipment by helicopter. On the morning of Tuesday, 21st March, there was an explosion in the fore-end of the after superstructure of the *Torrey Canyon* which killed the Chief Salvage Officer of the Dutch salvage crew. Attempts at salvage were continued, however, in spite of the difficulties caused by the ensuing lack of power on the ship, by the risk of further explosions of the volatile gases of the oil, and by the heavy swell which made it hazardous to get craft alongside in order to transfer the heavy equipment needed on board.

20. In the knowledge that the tides were daily becoming more favourable, and that the best chance of salvage would occur at the top of the spring tides on Sunday and Monday, 26th and 27th March, three compressors were placed on board by helicopter on Wednesday, 22nd, and plans were made to pump air into the tanks to give the ship sufficient buoyancy to lift her and to allow her to be pulled off the reef.

21. Late on Tuesday, 21st March, the Prime Minister asked the Government's Chief Scientific Adviser to review the technical and scientific aspects of the problems posed by the wreck, with a view to making immediate recommendations for action. The following day, Wednesday, 22nd March, the Chief Scientific Adviser convened an emergency Committee of Scientists and outlined to them the task of dealing with the problem on the assumption of the worst possible case, namely, that the ship would not be refloated and that means had to be found for disposing of her cargo. The problem was sub-divided into six parts; how to deal with the oil remaining in the ship; how to dispose of oil on the sea; how to prevent oil reaching the coastline; how to treat beaches which might be contaminated; how to obviate dangers to marine life; and how to co-ordinate the efforts of various bodies dealing with the threat to other wild life.

22. On Thursday, 23rd March, the wind, which remained W to NW, increased in force to 20 knots. Twenty-four ships were now engaged in spraying detergent on patches of floating oil, and the final preparations for salvage were in hand. The wind backed round to the SW on Friday 24th, pushing the oil slicks towards the Cornish beaches, where they arrived the next day, Saturday, 25th March. It was estimated that a further 20,000 tons of oil, over and above the 30,000 tons lost in the first few hours, leaked from the holed cargo tanks into the sea during the week following the accident, leaving about 70,000 tons of oil still on board the *Torrey Canyon*. A trial pull with three tugs was made before the main attempt at salvage, which was scheduled for Monday, 27th March, when the highest spring tide was due. Tanks were pressurised with air to increase the ship's buoyancy, but the tugs only succeeded in pivoting the vessel some eight degrees to starboard.

23. On Sunday, 26th March, a south westerly gale blew up and delayed a further attempt to pull the *Torrey Canyon* off the rocks until the late afternoon. The forward tanks were again pressurised, and four tugs were used. During the course of the operation, the cable linking the two largest tugs to the tanker was

broken. Shortly afterwards, at about 1800 hours the same afternoon, the *Torrey Canyon* broke her back and attempts at salvage were abandoned. As she broke a further large amount of oil, estimated at about 50,000 tons, was released.

24. The bulk of the oil released as the ship broke up came under the influence of a westerly gale-force wind which later veered WNW. This oil came close to the Cornish coast, but later, with the wind turning north-west to north on the 29th March, the main slicks were carried southwards towards France. The remainder of the oil already spilt (also about 50,000 tons; see paragraph 22), much of which had drifted up the north Cornish coast, was driven by the westerly winds on to the beaches. By Monday, 27th March, the coastline from the Lizard to Trevose Head (North of Newquay) was affected; in some places the pollution was very heavy; others escaped completely. From the point of view of what happened subsequently, it should be noted that the oil began to contaminate the beaches during the course of spring tides which happened to be the highest recorded for over 50 years. Because of this, pollution on parts of the first affected beaches (e.g. Sennen Cove, Whitesand Bay, Mounts Bay) occurred at heights which were subsequently unwashed by the sea. Furthermore, clearance had to be carried out during a period when the height of the tides was falling (from high springs to neaps). This added to the difficulty of the problem.

25. With the break-up of the ship, the plans prepared by the Chief Scientific Adviser's Committee were put into operation. It was clear that no further attempt at salvage of any part of the ship would be possible under the prevailing conditions, and since removal of the remaining oil into tankers standing by was also considered to be impracticable (see paragraphs 46-50), the only course left open was to try to burn the oil *in situ*. Just before the ship broke up, some of the salvage crew were still aboard. The vessel was not finally abandoned until the morning of Tuesday, 28th March.

26. By Monday, 27th March, the worsening weather, and the hazard of explosion, made any attempt to ignite the oil by charges laid on the ship, as had been planned (see paragraphs 61-65), too dangerous to contemplate. On Tuesday, 28th, experiments were made to see whether the oil already on the sea could be ignited with the aid of sodium chlorate 'tiles'. The experiments proved unsuccessful, probably because the highly inflammable volatile fraction of the crude oil had already evaporated.

27. At 09.35 hours on Tuesday, 28th March, the Treasury Solicitor was informed by the solicitor acting for the Dutch salvors that the salvage services had been terminated at 09.30 with the consent of the ship's owners. The Treasury Solicitor informed the salvors' solicitor that the United Kingdom Government had decided to endeavour to fire the oil remaining in the ship. The salvors' solicitor confirmed that he had already received notice of the warning to ships and aircraft to keep clear of the area.

28. The order was then given to bomb the *Torrey Canyon* with the aim of penetrating tbe deck above each undamaged tank and setting the remaining oil on fire. Precision bombing by Buccaneer aircraft was carried out on three consecutive days (Tuesday, 28th to Thursday, 30th March), and succeeded both in piercing all the tanks which still contained oil and in setting fire to it. Approximately 20,000 tons of oil was estimated to have been burned in the three days' bombing.

29. Naval forces continued to spray the oil slicks at sea until Tuesday, 4th April, a total of eighteen days. By that time the large patches of oil released on the break-up of the vessel had moved southwards, under the prevailing northerly winds, and were menacing the Channel Islands and the French coast. Spraying was continued inshore by chartered vessels, but by the first week in April, the main effort was concentrated on clearing the oil from the beaches and rocky coves round the Cornish coast, and on preventing the inshore oil from entering harbours and estuaries.

30. This task fell primarily to local authorities. They received great assistance from the Army and Royal Marines, over 1,400 men being employed in transporting materials and equipment, and in beach clearance and other work. Reconnaissances of 28 beaches and coves on the coast of Cornwall from Lizard Point (Grid reference 6911) in the South, to the Beacons (Grid reference 8466) in the North, were carried out hy units of the Royal Engineers between Thursday, 6th April, and Tuesday, 11th April, to determine the amount of engineering effort required to clear the oil from the worst affected beaches where it had often penetrated deeply. It was found that 14 beaches required no engineering work and that seven others were being tackled by local councils either working directly with their own equipment or operating through contractors.

31. As a result of trials carried out on Porthmeor beach (St. Ives), on 3rd to 8th April, by the Royal Engineers with the help of the Warren Spring Laboratory and local authorities, it was recommended that the top 12-inch layer of heavily contaminated beaches should be pushed by earth moving equipment to the low-water mark and sprayed with detergent. After the polluted sand and shingle had been washed by the tide, the whole area was to be chain harrowed and treated lightly with further detergent.

32. Using this laborious method on the heavily polluted beaches, and detergent and pressure hoses on those which were more lightly contaminated, the bulk of the oil on the more easily accessible beaches was cleared by the end of April, although some badly polluted rocky coves (e.g. Sennen Cove near Land's End) still remained fouled.

33. At the start, the Navy Department, which was the first to be called into action, was in charge of operations. On 20th March, the Parliamentary Under-Secretary of State for the Royal Navy met local authorities and established temporary co-ordination and control. From 24th March an emergency administration under the Minister of Housing and Local Government co-ordinated the activities of local authorities and the Services in the cleaning of beaches. Trihute should be paid to the Ministry's inspectorate who helped enormously in this task. The Ministry worked from local headquarters at Plymouth, Portsmouth and Folkestone, at each of which Ministers were in charge. Many private individuals and firms contributed labour, materials and equipment. Right from the outset, the representatives of all the Departments concerned, of the local authorities and of the three Services worked harmoniously and devotedly together, and their team work undouhtedly led to the speedy clearance of the oil from the sea and the beaches. Suggestions for dealing with the problems involved came in hundreds from all parts of the world. The Press was also active hoth in reporting and publishing suggestions. There was no lack of criticism about what was being done.

34. The Ministry of Agriculture, Fisheries and Food, and the Natural Environment Research Council took immediate steps to prepare a list of important conservation and fishery sites and to co-ordinate surveys of the effects of the disaster on marine and inshore life, and also made suggestions as to the best ways of dealing with the oil so as to protect commercial fisheries and coastal habitats of importance to conservation. The Nature Conservancy and the Royal Society for the Protection of Birds (RSPB) were jointly responsible for co-ordinating the work of rescue, treatment and rehabilitation of oiled sea birds, which was carried out by the Royal Society for the Prevention of Cruelty to Animals in association with the RSPB and other voluntary organisations.

35. Oil from the *Torrey Canyon*, driven by a north-westerly wind, reached the coast of Guernsey on Thursday, 6th April. The area mainly affected was the western and south-western coasts of the Island. Smaller quantities were washed ashore on 7th and 8th April.

36. Oil first reached the shores of Brittany on Sunday, 9th April, and was still coming ashore up to 28th April. It extended 60 miles from the Baie de Lannion in the West to the Pointe de L'Arcouest in the East. It also affected numerous off-shore islands. The pollution was reported to be thicker than in Cornwall, and virtually continuous along most of the affected coast. Some deposits were estimated to be up to 12 inches deep. By 28th April, 4,200 tons of oil were said to have been removed. Treatment was mainly by mechanical removal (often by hand raking and shovelling), and little detergent is said to have been used. The French Navy also treated much of the oil at sea with sawdust and other particulate matter, in preference to the use of detergent. The last oil slicks were finally 'sunk' by the French Navy in 1,000 feet of water in the Bay of Biscay in early June. It was believed that in these conditions any deposits likely to be formed would be so dispersed that they could not harm submarine fauna and flora, and that release of the oil would be minimal.

3. Disposal of the Oil in the Ship

37. There were three approaches to the problem of disposing of the oil in the grounded vessel: (a) to refloat the ship, or part of her, with as much as possible of her cargo, and tow her to sea where the oil could be disposed of without risk of shore contamination; (b) to pump the oil out into other vessels; and (c) to burn the oil in the ship where she had grounded.

SALVAGE OF THE SHIP

38. The majority of tankers which have stranded in the past few years (see paragraph 11) have been successfully refloated. Most of them had lodged on a relatively soft and flat part of the sea bed, and in many cases, depending on the ship's draught, the availability of pumps for shifting cargo in order to change trim, the state of the tide on grounding and the conditions of sea and weather, were refloated with the minimum of external assistance. Salvage has been successful even in more difficult cases. Thus the floatable fore section of the Norwegian tanker *Anne Mildred Brøvig*, which was in collision in the Elbe estuary on 20th February 1966, was successfully cut from the remainder of the ship and salvaged with 14,000 of the original 39,000 tons of oil on board. However, this operation took two and a half months, and 7,500 tons of oil had to be pumped out to give the recovered section sufficient buoyancy to be towed to port.

39. Experience thus provides good reason for supposing that the chances of salving a stranded tanker and her cargo are good. It is right, therefore, that every effort should normally be bent towards salvage in order both to save a stranded tanker and to avoid large-scale pollution. This was the first course which the Government necessarily had to try in the light of the professional advice it had been given. The stranding of the *Torrey Canyon*, however, was no ordinary accident. As mentioned earlier (paragraph 14) it was known that the vessel had hit the Seven Stones Reef at near full speed (approximately 16 knots) and that investigations by the salvage teams had shown that very extensive bottom damage had been caused. A number of deep penetrations of the ship had been made by pinnacles of the reef which intruded many feet into the hull (approximately 15 feet into No. 1 tank bay and 5 to 10 feet into No. 5 tank bay). Of the 16 oil-filled tanks, it was believed that at least 12, and possibly 14, had seriously damaged bottoms. Oil contained in a tank which has sustained only localised bottom damage does not, of course, pour out into the sea, since being lighter, it floats on water.

40. Drawings from Lloyds Register made available to the Committee of Scientists, showed that the ship was very strongly built. The steel deck plates were between 1.25 and 1.33 inches thick and the sides of the hull between 0.75 and 1.00 inch, depending on the position of the plating on the hull. Furthermore, the tanker had an extremely robust internal structure both in the form of strong diaphragm plates and longitudinal stiffeners, some of which were 10 feet deep. All the plates were braced by stiffeners of some 20 inches depth at a close placing, interspersed with stiffeners of about 3 feet in depth. As the tanks were vapour

tight, air could be pumped into them to displace oil or water so as to provide extra buoyancy. It was for this reason that the commercial salvors hoped that the ship could be floated and pulled off the rocks during the course of the high tide on Monday, 27th March.

41. Although the Committee of Scientists and the Chief Naval Salvage Officer agreed that this was a reasonable possibility, they took a less optimistic view of the chances of success. They based their belief not only on an appreciation of the energy dissipated when the ship struck and that this had occurred near high water, but also on a first-hand description of the way in which the tanker was held on the rocks. What was not available, however, when the Committee first met on 22nd March, was a quantitative estimate of the extra buoyancy which would be required to lift the ship clear at high tide, and how this might be obtained without deliberately discharging an excessive amount of oil. If the required buoyancy could not be provided, there seemed little likelihood that the ship could be pulled off the rocks by brute force, even if the necessary power could have been generated, because no available cables were likely to be strong enough. As already noted, two attempts to pull the ship off on 25th and 26th March, before she started to break up, were unsuccessful, even though some of the tanks had been pressurised with air to increase buoyancy.

42. Before these final attempts at salvage took place, it was thought that there was a possibility, given calm weather, that the ship might be cut in two in order to save part of her, as had been done in the case of the *Ann Mildred Brøvig* (see paragraph 38). It was believed that this could be done using explosives (i.e. linear shaped charges of plastic explosive) and that there was a good chance that firing the oil during these operations could be avoided. The cutting charges could, of course, only be used to sever the deck and hull plates and not the bottom plates. Further examination revealed, however, that the internal bulkheads and main longitudinal stiffeners (see paragraph 40) would defeat any attempt to tow away the more easily floatable part of the ship; and it was quite impracticable to consider entering the tanker in order to sever the internal members. Any kind of cutting which involved having men on the wreck was ruled out on safety grounds. In addition, there were considerable doubts about the practicability of towing away part of the ship, even if it could be completely separated, because of the rocks which penetrated the hull. This course of action was, therefore, not recommended.

43. Nevertheless, plans had to be made for the disposal of the ship and her remaining cargo if she were pulled off the reef. The estimate was that she would float, but that her mean draught would be just over 60 feet (normally 45 feet), and that she would be down by the head to between 75 feet and 85 feet. She would be effectively 'waterlogged', floating only by virtue of the fact that her deck was still intact.

44. Quite apart from the danger of explosion of petroleum vapour, the increased draught of the ship meant that there was no convenient shore installation in the United Kingdom where she could lie alongside to enable the remaining oil to be pumped out. Sheltered deep water would have to be found which would give the opportunity of pumping out in one of the ways described in paragraphs 46 to 50 below. Mounts Bay and Milford Haven were the only suitable places anywhere near.

45. Even in these two waters, it was questionable whether the weather would stay calm throughout the time required for pumping. There was also the obvious and grave danger that the ship might break up during the tow and by so doing create an even more serious problem. It was concluded, therefore, that if the ship, or part of her, were in fact refloated, the best course would be to tow her as far out into the Atlantic as possible, and then to sink her. This would release oil, either then or later (the tanks would be expected to rupture at between 1,000 and 2,000 feet depth), but it could be hoped that natural dispersal of the oil far out to sea would avoid serious pollution of the coastlines of North-West Europe, including the British Isles. The risk of serious pollution might have been reduced by the placing of destructive charges on the deck to allow the oil to be ignited in the tanker and on the surface of the sea as the ship sank. Though this would not burn all the oil, it would be expected that a major portion could be destroyed in this way.

THE POSSIBILITY OF PUMPING OUT THE OIL

46. Transfer of the remaining crude oil from the *Torrey Canyon* to another tanker or tankers could, in principle, have been carried out either by laying a receiving ship alongside and pumping the oil into her, or by mooring a receiving vessel some distance away and pumping the oil either through a pipeline laid on the sea bed or, better still, through a floating hose.

47. Both of these possible courses of action were greatly complicated by the fact that the ship's engine room was not only partly flooded, but also full of petroleum vapour which could have led to a fire or a further explosion if attempts had been made to restart the shut down boilers. The main pump room aft was flooded to sea level with crude oil, and the auxiliary pump room forward was open to the sea. The *Torrey Canyon* therefore had neither power nor pumps. The ability of a receiving ship to remove oil by suction from a damaged tanker depends upon the suction head necessary to raise the oil from its level in the tanks and to draw it over the tanker's deck and across to the receiving vessel. This method is particularly appropriate when dealing with cargo compartments open to the sea, and where the sea can therefore flow in underneath the oil and so maintain the level of the oil surface. As previously explained, the oil will remain as an intact layer floating on top of sea-water because of its lower density. In an undamaged compartment the suction lift required would become insupportable, so that the level would have to be maintained by deliberately running water into the bottom of the compartment. If, for any reason, the oil cannot easily be removed by suction from a damaged tanker, as was the case in the *Torrey Canyon*, the alternative is to 'blow' it out with pumps submersed in the oil (liquids can be 'blown' to much greater heights than they can be sucked as with fire hoses). Unfortunately, the rating of the submersible salvage pumps which were available was only about 30 to 50 tons per hour. The problem was to deal with 70,000 tons which were estimated to have been still present in the stranded ship before she broke up (paragraph 22).

48. The possibility of putting another ship alongside the wreck was ruled out for the following main reasons:

(a) A difficult and dangerous survey had shown that the rocks would not allow any ship much bigger than a tug alongside, so that the number of trips which would have been needed to clear all the oil was unacceptable in the circumstances.

(b) Even during the fairly fine weather which prevailed in the first two or three days after the accident, there was a ground swell over the rocks, causing the *Torrey Canyon* to roll and heave. Furthermore, transfer of the oil might have caused additional movement. Another ship, afloat in the vicinity, would have been even more 'alive' and it was considered that it would have been impossible to keep her alongside without considerable risk of being holed.

(c) The receiving ship would have had to supply compressed air for driving petroleum-safe, portable, submersible salvage pumps which would have had to be operated through the opened tank lids. As mentioned above, the transfer would have been very slow with the equipment which was available. It was estimated that a total of 350 pumping hours (15 days) would have been required to move the 70,000 tons which it was estimated were still in the ship.

49. The second alternative of mooring a receiving vessel some distance away might have been feasible, given time. A tug or wheeler vessel would have had to lie alongside the *Torrey Canyon* to control the operation and to supply air for the petroleum-safe portable pumps. However, the following considerations had to be taken into account:

(a) The receiving vessel would have had to lie at least 1,000 feet away from the Seven Stones Reef to be safe, and could have remained as close as this only if the weather and sea had allowed (wind under 20 knots).

(b) A floating hose at least 1,200 feet in length would have been required. Ordinary hose can be fitted with floats, but this operation would have taken two or three days. The hose would have been extremely vulnerable to weather, and in anything higher than three or four foot waves (slight sea) would have had to be protected by supporting vessels.

(c) For submerged pipeline, the sea-bed would need to have been accurately surveyed, and at least 1,000 feet of pipe prepared. It was estimated that this would have taken at least a week.

(d) With the pumps which were available, the transfer rate would have been even slower than indicated in paragraph 48(c) because the oil flow rate would have been reduced by the pressure loss through 1,000 feet or more of pipeline. The best estimate of the possible pumping rate was 100 tons per hour, or 700 hours (30 days) to clear the ship.

50. Fleet Auxiliary refuelling-at-sea methods of transfer were also considered, but these depend upon both ships being able to keep station. Since the tanker was a stranded wreck, the receiving ship would have had practically no scope for manoeuvre.

DISPOSAL OF OIL BY BURNING

51. From the outset, while the ship was still held on the rocks, with her deck above high water, attention was given to the possibility of disposing of the remaining oil by burning, and plans were laid for this course of action (see

paragraphs 56-64). Burning was not open to the objection that the ship would sink in the process; she was well held by the rocks. Convincing data were not available to allow an evaluation of the rate at which the oil in the tanks would burn or how much would finally burn. The main doubtful factor was the dependence of the rate of burning on the proportion of the tank laid open to the air. Indeed the only previous record of large quantities of oil being burnt in a stranded tanker was at first sight not very encouraging (see paragraph 57). At the same time it was necessary to consider whether the oil in the *Torrey Canyon*, if set ablaze, would pollute the air over Cornwall, the Channel Isles, or even the French coast. Preliminary assessments showed, however, that air pollution overland and at sea from the fire, although it might be unpleasant, would not be hazardous to health, and that it would be more acceptable than the coastal pollution which might result from the release of the remaining quantity of oil into the sea.

52. Under the very worst conditions (burning rate of 10,000 tons of oil per hour giving 500 tons of carbon; stable conditions; an inversion layer at 1,000 feet, i.e. a layer in which the temperature of the atmosphere increases, instead of falling, with increasing altitude, and thus tends to act as a barrier to upward movement of smoke; and wind speeds of 10 knots, about 12 miles an hour) it was calculated that the smoke from such a fire over a period of a few minutes would reach its highest concentration (76 milligrams (mg)/cubic metre) 6½ miles from the site of combustion. The concentration would remain at this level for only a few minutes. Moreover, since inversion layers over the sea are normally weak, it was likely that they would be penetrated by the smoke plume from the burning oil. The nearest point of Cornish coast from the Seven Stones Reef is about 13 miles away. If one assumed no inversion layer and a wind speed of 25-50 mph, calculations showed that the smoke concentration at Land's End would have risen to a maximum of only four to five mg/cubic metre. At Penzance this would have dropped to about one to two mg/cubic metre. All this indicated that if the oil were successfully set alight atmospheric pollution overland would be of short duration and only twice to four times higher than the average winter smoke conditions in many industrial cities.

OTHER ACTIONS CONSIDERED

53. In the early stages after the stranding, the Royal Navy considered containing the discharged oil from the *Torrey Canyon* by placing a boom around the ship. Such devices had previously proved successful in the Persian Gulf and elsewhere, especially in harbours. Mainly because of the high cost of maintenance, however, they had been installed in only four of the ten British harbours handling crude oil. All previous experience of such booms applied to relatively calm waters, and although they had been shown to present a hazard by retaining spillages of low flash point (as shown by a fire in 1960 in Milford Haven), the Ministry of Defence placed an order on 21st March for 3,000 feet of a boom made of expanded Aeroprene blocks supporting a skirt six feet deep. This was not delivered to Falmouth until 28th March, and could not, therefore, be used round the *Torrey Canyon*. It was used later, however, at the mouth of the Fal estuary and at Looe.

54. Another possibility for dealing with the oil left in the *Torrey Canyon* was to

immobilise it by gelling, freezing or mechanical means. Freezing techniques (e.g. by the use of solid carbon dioxide), even if they could have been applied on the scale required to deal with the oil, might have induced brittle fracture of the ship, and were therefore considered impracticable. In view of the extensive damage to the ship, so were mechanical methods, such as bolting plates over the holes to reduce the outflow of oil. Crude oil can be gelled by suitable chemical treatment, but each variety of oil requires a gelling agent tailored to fit its own physical properties, and more important, extensive power is required for mixing. The technique also has the disadvantage that the gelled oil cannot then be discharged to lighten or trim the ship.

4. Explosive Surgery of the Ship

55. It seemed clear, if salvage was not going to work, that by far the best way of disposing of the remaining oil would be to burn it *in situ*, and for this to be successful some opening of the deck would be necessary to provide the supply of air that would be required.

DESTRUCTION OF OIL CARGOES

56. Kuwait crude oil in its initial form, i.e. before weathering, is highly inflammable since, like all other crude oils, it is a natural mixture of hydrocarbons ranging from highly volatile components such as aviation spirit to solid materials such as bitumen and paraffin wax. Tests showed that, if ignited, fresh Kuwait crude would burn almost completely while floating on water, leaving less than one per cent residue. If, however, crude oil is exposed as a thin film for some time to the atmosphere, it quickly loses the more volatile fractions which are easily set alight, and the remainder consequently becomes progressively more difficult to burn. As little as thirty minutes is needed for crude oil to lose the highly inflammable fractions when spread out on the sea. It, therefore, followed that if burning was to be successful, the oil either had to be ignited in the ship itself or within a very short time after it had left her. Furthermore, the greater the mass of oil that could be ignited at one time, and hence the more extensive the fire, the greater would be the chance that the remaining oil would be completely destroyed.

57. Evidence from previous tanker accidents indicated that ignition of the oil in a few tanks does not necessarily lead to ignition or explosion of the oil in the other tanks. For example, the fire which started in the after part of the *SS British Crown* at Umm Said on 20th August, 1966, did not lead to the burning or explosion of the oil (10,000 tons) in the intact forward tanks. Moreover, the oil which burned in the tanks did so only slowly. About 10,000 tons was consumed in the first week, and the remainder (5,000 tons) over the succeeding two months. The decks of the ship above the after tanks were not deliberately ruptured to allow the free entry of air. It is possible that in this case combustion was maintained largely because of the high air and sea temperatures which prevail in the Persian Gulf.

58. In view of this evidence, it was considered important to attempt to ignite the oil in all the *Torrey Canyon's* tanks simultaneously, and, at the same time, to open as much of the deck as possible to provide a copious draught of air to keep the fire burning strongly. It was realised that boarding the ship after the initial firing, in order to restart a fire which had gone out, would not be practicable until all possible danger of further spontaneous fire or explosion had disappeared.

EXPLOSIVE SURGERY OF THE SHIP

59. Ways were therefore examined of opening up the deck plates of all the sixteen tanks which had been full of oil. The operation had to be carried out in a way which prevented entrapped pockets of unburnt oil being left floating above the water surface and which at the same time minimised damage to the

hull, so that the oil, while burning, was contained in the tanks for as long as possible. By doing this it was hoped to produce the fiercest possible fire.

60. When the problem was first examined by the Committee of Scientists on Wednesday, 22nd March, the ship was in one piece, the weather was calm, and boarding for demolition purposes was quite practicable. The two main methods considered were:

(a) cutting the deck plates by line charges so that large holes would be made above each tank, followed by ignition of the oil in each tank by a separate device; and

(b) wholesale disruption of the deck plating by a massive charge placed either inside or outside each tank with simultaneous ignition of their contents.

61. After careful consideration, the first method was discarded. Tests showed that the strength and spacing of the vertical stiffening plates under the deck would mean that only small holes could be made, even with quite complicated arrangements of cutting charges. Small holes would not have provided sufficient draught of air to maintain combustion, particularly when the tide ebbed and the oil level dropped below the deck level. It was also believed that the installation of the charges would take too long, bearing in mind the complexity of such a demolition operation and the state of the ship.

62. Attention was, therefore, focussed on the second method. So long as the ship was still in one piece, the hatch covers of the tanks could be lifted, provided the tanks were first depressurised. The loss of buoyancy arising from depressurisation was not expected to be serious while the weather was calm. Once the hatch covers had been removed, large high-explosive charges could have been placed inside each tank, and fired at high water when submerged in the oil, so as to generate the maximum disrupting effect by the liquid displaced by the explosion. The deck plates of the tank would be more vulnerable to an internal than to an external explosion, and the plates might well have ripped away, at least partly, from the strong stiffening members. The size of the explosive charge needed for each tank was estimated as at least 150 lb. Alternatively, if handling difficulties could have been overcome, a 1,000 lb. bomb in each tank might have been used. It was recommended that flash charges should be incorporated with the demolition charges, or an aluminised filling used in the bombs, to ensure ignition of the oil.

63. An alternative approach, which was considered, was to place demolition charges on the deck, tamped as much as possible with sandbags to promote downward destruction of the deck plates. It was estimated that at least 150 lbs. of explosive charge would be necessary above each tank to produce sufficient destruction. But model tests, which were completed only after the bombing attack (see paragraph 67) had started, indicated that this amount of charge was only just sufficient to penetrate the tank deck and cut through the supporting members.

64. Since it would not have been possible to board the ship once a fire had started, it was agreed that demolition should, if possible, be staged as one 'set piece', with all the tanks being blown at the same time. The use of time-controlled and/or remote-controlled ignition of the demolition charges was therefore necessary and preliminary arrangements were made for them to be available.

65. On Sunday, 26th March, this plan had to be modified when the vessel started to break into three pieces (see paragraph 23). If 'explosive surgery' was to be carried out at all, the ten tanks which then remained would now have to be blown open using heavily tamped explosive charges placed above the deck. This operation could not be carried out in rough seas, and would have to be done at low tide, because of the way the three pieces of the ship now lay. Even so, the operation would have been both difficult and hazardous because the oil-covered, sloping decks were now awash, and there was some possibility of spark ignition of the petroleum vapour. As the weather worsened, it became clear that this course of action also had to be abandoned.

BOMBING OF THE SHIP

66. The possibility of bombing the tanker from the air had also been considered from the start, and it was decided that this was the only reasonable treatment left, provided that big high explosive bombs with aluminised fillings to ignite the oil were used in fairly large numbers. The difficulty here was the precision needed in aiming the bombs at not very clearly defined targets. The deck above each of the intact ten tanks had to be penetrated and opened, preferably towards the raised ends of the tilted decks, without either destroying more of the ship under water or disrupting her sides and so releasing her contents into the sea without burning. Bearing in mind the small target each tank presented, and the difficulty of recognising its exact position, it was clear that multiple attacks were called for. Ideally the ship would require inspection after each attack, to ascertain which tanks might still need further bombing.

67. As already observed, bombing started at low water on the afternoon of Tuesday, 28th March, when some forty 1,000 lb. HE bombs with a 35 msec. delay were dropped by Royal Navy Buccaneer strike aircraft. After the first four hits, the flame and smoke of the burning oil made it difficult to aim subsequent bombs, but, nonetheless, it was estimated that thirty hits were scored. To help maintain combustion, under-wing fuel tanks were jettisoned by RAF Hunter fighters on to the sea up-wind of the fire, some 5,400 gallons of aviation fuel being used. Fires continued to burn for two hours round the wreck. The following day, when oil was still seen to be coming from the wreck, bombing was resumed using napalm bombs as well as high explosive bombs and fuel tanks. RAF Hunters also used rockets to open up the wreck still further. The wreck again burned over its whole length, but the fire died down by the evening when further direct hits by Buccaneers caused no further ignition. The attacks were resumed on 30th March, but no fires were started. The wreck was then presumed to be free of oil.

68. In case the aluminised bombs, aviation fuel and napalm did not ignite all the oil, it had also been recommended that additional incendiary devices should be made available to ignite oil either on the ship or floating on the sea. After the first bombing attack, devices containing sodium chlorate, developed by the Royal Armament Research and Development Establishment (RARDE), were accordingly dropped by helicopter on to patches of oil exuding from the ship. They were successful in igniting the oil. As mentioned earlier (paragraph 26), this method had not worked when used on oil which had moved far away from the ship and which had therefore already lost most of its volatile components

through evaporation. Sodium chlorate was not, however, again used because of the continued success of the bombing.

69. It would clearly have been advantageous—and was originally recommended—that external inspection of the ship should be made by a Naval diving team at the conclusion of each set of attacks. This was expected to be a dangerous job in the sea conditions prevailing, and after the first attacks the added hazard of possible unexploded bombs in the vicinity caused the postponement of inspection until all attacks had been finished. As it turned out, the inspection could not be carried out until the 14th and 15th June, when an eight-man team of naval divers thoroughly surveyed the remains of the wreck, then 65 feet down, and finally concluded that no further oil was on board.

70. Thus, the first major lesson which can be drawn from the *Torrey Canyon* incident is that large quantities of crude oil in a stranded or wrecked tanker can be successfully burned by bombing so as to leave little residue. Provided the tops of all the tanks can be opened sufficiently to allow the entry of adequate quantities of air, and the sides of the tanks left intact so as to contain the burning oil as much as possible, the conflagration will be confined to the ship and the water immediately surrounding her, and burning will be substantially complete. It is nevertheless likely that if circumstances had permitted their use, demolition and ignition charges placed aboard the vessel would have been both more effective and cheaper in burning the oil than was the bombing.

5. Treatment of Oil on the Sea

71. Unless it has an unusually high viscosity, crude oil will spread on sea water either as a homogeneous film or as an oil-in-water emulsion stabilised by naturally occurring emulsifiers present in the sea, the degree of emulsification usually increasing with time. The rate of spread of unemulsified oil is approximately proportional to the thickness of the film, but is influenced by the physical and chemical properties of the oil and by wind speed and current. The final thickness of an oil film may vary from one micron to about one millimetre (from 40 millionths to 4 hundredths of an inch), so that one ton of oil could eventually cover an area of sea up to nearly one mile square. From the point of view of the pollution of a coastline due to large spillages, spreading as such is probably less important than the movement of oil as homogeneous slicks or emulsions of oil, through the action of wind, tide and current. This kind of movement can be calculated, and in the case of the *Torrey Canyon* the course of the large patches of oil which drifted across the Channel was accurately predicted by members of the Marine Biological Station, Plymouth with help from the National Institute of Oceanography (Natural Environment Research Council). Further refinements are now being tried, using computers, in order to predict 'local' movemeut (i.e. movement over a few square miles), which might be useful in directing spraying operations at sea, given any future incident.

72. As a result of the work of the Warren Spring Laboratory, and from later trials carried out in collaboration with the Royal Navy, measures had been agreed, as already mentioned (paragraph 7), for dealing with floating oil. Spraying with a mixture of an emulsifier and a suitable solvent (detergent), and subsequent agitation of the surface either with the screws of the spraying vessel or with a powerful jet of water, results in the oil being dispersed into extremely small droplets coated with emulsifier which prevents them coalescing into large globules or patches. When such an oil-in-water emulsion becomes very greatly diluted, as happens at sea, the film of oil in due course disappears completely.

73. This method was successfully used in all the spillages mentioned in paragraphs 8 and 9. Spraying with agitators has also been frequently carried out during the past year by the Milford Haven Harbour Board, with most satisfactory results. The German report to IMCO on the *Anne Mildred Brøvig* stated that the leakages of oil which occurred during the salvage operations were also quickly and effectively dispersed by the use of detergents. Since the natural action of the sea also leads to the disappearance of patches of oil, the amount of detergent which is required decreases the longer treatment is delayed. Both the cost of detergent and the fact that above a certain level of concentration it can poison marine life thus argue for delay in application. But delay is unacceptable if the risk of subsequent and serious coastal pollution were thereby to be increased.

74. There is a need for further research to establish the critical time factor upon which decisions regarding the spraying of detergent should be based. Crude oils and their residues vary widely in their composition, and so in the rate at

which they disappear as a result of the natural action of the sea. A relatively low content of residuals (substances boiling above 700°F (or 400°C)), as in Libyan oils, will result in more rapid loss of the bulk of the oil by evaporation; a higher sulphur content, as in Kuwait oils, confers greater resistance to oxidation; the high values for asphaltenes found, for example, in Venezuelan oils increase the rates of spreading and emulsification.

75. Within a few weeks of exposure on the surface of the sea, a relatively large fraction of the original crude oil disappears through evaporation, solution in sea water, oxidation, bacterial digestion, dispersion and absorption on the surface of plankton and organic debris. These processes even act on the so-called persistent oils (i.e. those which do not readily evaporate), but the exact way they operate is not yet known. The oil from the *Torrey Canyon* formed an extremely stable emulsion of water-in-oil (i.e. an emulsion consisting of water droplets surrounded by oil) containing from 30 to 80 per cent water, which is now generally referred to as 'chocolate mousse' (see paragraph 111), and which seems to have been stabilised by agents such as bacterial slime, plankton and organic debris. It is unlikely that the formation of this kind of emulsion was in any way accelerated by the use of detergents. It seems to be formed only when very large amounts of oil are spilt, and it greatly extends the time of survival of the oil on the sea.

TREATMENT WITH EMULSIFIERS

76. The Admiralty Oil Laboratory had prepared specifications for cleansing agents (detergents) for the removal of oil primarily designed for use on Her Majesty's ships for tank cleaning, and also for the removal of oil contaminating the superstructure. The main cleansing agent used (Gamlen), although intended for purposes which justified an expensive and sophisticated detergent (i.e. 10-20 per cent solution of an active chemical (emulsifier) in a mineral solvent) is also very effective as an emulsifier of floating oil. All naval dockyards keep a small supply of material in stock. It is because of this that only four hours after the tanker was reported aground on the Seven Stones Reef ships of the Royal Navy were able to leave Plymouth loaded with the detergent and suitable spraying equipment to treat the oil which was pouring from the stranded vessel.

77. All available stocks of Gamlen were used in the first day of spraying, and the Stores Department of the Royal Navy, therefore, got in touch with the major manufacturers and ordered such supplies of other detergents as were immediately available in large quantities. Within about ten days, total delivery rates of various kinds of detergent approached one hundred thousand gallons per day, thanks largely to the hard work and skill of police, fire and civil defence services in keeping the routes to the ports clear. The main detergents which were made available and used up to 6th April are shown in Table 1 on page 22.

TABLE 1

Quantities of Emulsifier-Solvent Mixtures used during the 'Torrey Canyon' Emergency (Up to 6th April)

Make†	Proportion* Emulsifier %	Aromatic* Content %	Amount Issued (Thousand gallons*)		
			Sea Use	Shore Use	Total Quantity
BP 1002	20	66	250	540	790
Dasic	25	High	180	400	580
Gamlen	30	24	36	75	111
Dutch	—	—	66	—	66
Atlas	30	8	5	45	50
Petrofina	8	15	15	34	49
Basol	15	82	4	44	48
Gramos	—	—	25	20	45
Other makes	—	—	11	6	17
TOTAL (thousand gallons)			692	1,164	1,756

† Emulsifier-solvent mixtures as supplied.
* Information from Admiralty Oil Laboratory.

By 17th April, a further 500,000 gallons had been issued for shore use, and it is estimated that a total of 2.5 million gallons of detergent was issued during the whole operation.

78. A member of the Warren Spring Laboratory staff was at Plymouth from the 20th March to assist in the planning of the spraying programme. The dockyard prepared and improvised large numbers of spray booms to mount on each side of the spraying vessels. The necessary pumping equipment was either purchased or provided by modifying existing pumps. It was also necessary to amass a spraying fleet and eventually up to 42 ships were used, 29 for offshore and 13 for inshore use. Owing to the dual need of maintaining spraying equipment and of operating on a cycle (two days on, one day off), the full number employed at any one time was never more than 25. In addition to the Naval vessels which were employed in the operation, fishing boats from the Cornwall area were chartered and fitted with spraying equipment. Diesel-driven fire pumps were fitted in several ships in order to agitate the surface of the detergent-treated patches of oil with hoses. At the peak of the operation nearly 50,000 gallons of detergent were used each day on the sea.

79. It is difficult to provide a numerical estimate of the success of this operation. What soon became clear was that when the spraying and subsequent agitation were correctly carried out, the dispersion was permanent. When the spraying off Cornwall was in progress, aerial observations indicated that the spraying vessels made clear wide tracks through dense layers of oil, and closely observed operations, particularly in Mounts Bay, showed that when a discrete patch of oil was thoroughly dealt with, it soon disappeared. But the persistent fresh westerly winds so extended the total area which was polluted, especially along the north Cornish coast, that the spraying fleet, which was mainly concentrated between the vicinity of the wreck and Penzance, was incapable of dealing with it all.

80. The earlier Warren Spring Laboratory experiments had shown that in order to emulsify floating oil at least one part of detergent is required to four parts of oil. Detergent was sprayed at sea at maximum intensity for perhaps 15 days. During this time some 700,000 gallons, i.e. 3,500 tons, were used. This amount could be expected to have emulsified at least 15,000 tons of the oil spilt at sea. As mentioned earlier (paragraph 24), the main pollution of the Cornish coastline was caused by the 50,000 tons or so of oil which was released from the vessel prior to her breaking up on the 26th March. Assuming that about a third of this was dispersed by evaporation and other natural processes, it is clear that the spraying with detergent prevented a considerable part of the remaining amount of oil which might have been washed ashore from doing so. In fact it is estimated that perhaps only about 20,000 tons of oil finally reached the coast.

81. During the course of the incident, the special virtues of many particular detergents were urged by chemical firms from all over the world. Thirty-seven of these were duly tested by the Warren Spring Laboratory, which in most cases was unable to demonstrate that they had any greater practical merit than the materials which were actually used. A very small number did have markedly superior emulsifying qualities; but this advantage was generally offset by higher costs or by the presence of chlorinated solvents which made the proposed material even more toxic than ordinary detergents to fish and other wild life. In practice, the process of emulsifying oil on the sea is inevitably inefficient because of the paucity of detailed knowledge of the changes that are taking place from moment to moment and place to place in the thickness of the oil film, and hence because of a lack of guidelines as to the correct rate of application of detergent. The choice of material, therefore, tends to be biased from the more costly and highly effective materials towards the cheaper but still reasonably effective ones. The principal disadvantage of all the materials used lay in their toxicity to marine life (see paragraph 129). This consideration, however, is not as important in spraying operations on the open sea as it is inshore. The total amount of detergent used at sea during the *Torrey Canyon* incident would have been diluted to less than one part per million given that it had been dispersed over an area of water 20 miles square, down to a depth of 10 feet. At this dilution detergent is not lethal to molluscs (e.g. cockles) and crustaceans (e.g. lobsters) (see paragraph 129) and probably not to plankton or fish.

OTHER METHODS OF DEALING WITH OIL ON THE SEA

82. In the earlier research work referred to in paragraph 7, the Warren Spring Laboratory had also considered various other means of dealing with floating oil. These were:

(a) mechanical removal;

(b) sinking with powdered solids; and

(c) the use of scavenging materials.

During the course of the *Torrey Canyon* incident, many variants of each of these approaches, and frequently the same ones, were suggested by industry, Government establishments and the general public. A number of these suggestions were tried out by the Warren Spring Laboratory.

83. Numerous proposals were also received either about collecting and confining the oil by some form of boom, or about skimming, scooping or sucking a mixture of oil and water from the sea surface and subsequently separating the oil and water. Most appear attractive at first sight, but unfortunately, none has been developed for use except in conditions of almost flat calm. One major oil company has a launch, stationed in Rotterdam which is fitted with booms and a suction device which very satisfactorily clears oil in a harbour, but which cannot be used with waves exceeding six inches or so in height. Similar equipment is owned by other companies.

84. A different device is used for the same purpose in Baltimore Harbour in the United States of America. This consists of a shallow draught boat on the front of which is mounted a roller dipping into the sea. The roller is preferentially wetted by the oil film, and on rotation, the oil is scraped off the roller inboard. Again, this vessel is suitable only in calm water.

85. No oil clearing vessel was available, or known, which could have been used in the conditions of the *Torrey Canyon* incident. Any such ship would have had to have a large oil recovery rate if it was to collect the oil sufficiently rapidly to prevent pollution of the coastline. (The pick-up rate of the harbour skimming vessels mentioned above is quite low, probably less than 10 tons per hour.) It would also need to have a large storage capacity for the oil it recovered if it was to remain on site for sufficient lengths of time. This would require either the provision of a shipboard oil-water separator, or a multi-tank vessel whose tanks could be used as simple gravity separators. Alternatively, the oil, collected by the recovery vessel at the site of the operation, would have to be off-loaded into other craft or into floating collapsible rubber containers which could shuttle the recovered oil to some nearby refinery or other suitable storage site.

86. Such a recovery ship would also need to be able to skim oil in sea, swell and wind conditions with wave heights up to eight feet and with periods of seven seconds, in such a way that the amount of water collected with the oil was minimal. This might be difficult to achieve because of rapid thinning of oil on the surface of the sea, and because oil on the sea can form, as mentioned earlier, water-in-oil emulsions containing up to 80 per cent water.

87. Another requirement would be that the scavenger vessel, if it could be designed, would have to arrive very quickly at the site of the pollution. It would therefore require powerful engines. It is unlikely that any scavenging would be feasible or practical during the hours of darkness, unless it were possible to illuminate areas of severe local pollution. All in all, there seems little prospect that any effective method for scavenging oil from the sea could be devised which could be used in conditions as adverse as those experienced during the *Torrey Canyon* operations. According to reports, the French succeeded in removing some oil from the surface of the sea by pumping it into a tanker equipped with two groups of pumps having a capacity of 200 tons per hour. This operation was carried out in relatively calm waters (two to four foot waves) and it seems highly unlikely that it would have proved effective in the much rougher seas round the Seven Stones Reef.

SINKING THE OIL

88. It is known that oil floating on the sea can be sunk by treating it with any fine granular material of high density to which the oil adheres. Many suggestions that this treatment should be applied to the *Torrey Canyon* oil were sent in. Ideally, the submerged mixture of oil and powder should set or congeal to a solid mass in which the oil is completely immobilised. Unfortunately, none of the materials which had been tried up to the time of the *Torrey Canyon* accident, for example, sand and cement, was suitable to the circumstances. Experiment had shown that although much of the oil in a patch could be sunk, subsequent agitation, by waves or currents, always brought some of the oil back to the surface. The main difficulty is that much less powdered material is necessary to sink the oil than is required to immobilise it permanently. The suggested use of less dense materials to overcome this shortcoming suffers from the drawback that they are difficult to apply in a uniform way and in sufficient amounts. Moreover, fishermen object to the sinking of oil on fishing grounds around the British coasts, firstly because it may have deleterious effects on creatures which live on the sea-bottom and, secondly, because of the possibility of subsequent fouling of nets and fishing gear dragged along the sea-bed. It was for a combination of all these reasons that no attempt was made round the Cornish coast to sink the oil from the *Torrey Canyon*. The method was successfully used later by the French to sink oil with powdered chalk in the deep waters (1,000 feet) of the Bay of Biscay, where apparently there is no risk to fisheries.

89. Three of seventeen new materials for sinking oil which were tested during the incident were found to be promising. The first is a sand coated with finely divided carbon to which the oil adheres (this has been used fairly successfully in harbours in the United States, but not in the open sea); the second is a 'stucco' which absorbs oil, sinks, and then sets fairly hard on the bottom; the third is a material made by treating pulverised fuel ash with a silicone compound which makes it float on the surface of the water until it absorbs oil, when it sinks to the bottom. The main problems associated with this product are the cost and the tremendous volumes of material which would be needed, the required ratio of ash to oil for optimum treatment being 6 to 1.

90. A suggestion was also made that some of the sinking materials which might have been used could have been treated with a culture of oil-feeding bacteria, so that the absorbed oil would have been consumed on the ocean bed. Although this idea is being pursued further, the chances of success are not believed to be high. Unless the oil is paraffinic or contains simple side chains, bacterial attack is difficult, and when the oil is viscous, particularly slow. Furthermore, the action of most of the bacteria known to attack oil, other than the natural bacteria present on the sea bed, is inhibited by the low temperature of the sea, especially in very deep waters.

SCAVENGING

91. The use of scavenging materials also looked an attractive way of dealing with the problem. Scavenging is the use of a low-density solid which absorbs the oil on the surface of the sea and remains floating. The resulting oily mass can then be more easily removed than can untreated oil. A number of materials are reasonably satisfactory for this purpose and 19 were examined during the

incident. The first to be generally employed, particularly by the oil companies in enclosed waters, is hay or straw. This is strewn over the oil slick and absorbs a considerable quantity of oil. It can then be collected by rakes, and has the further advantage that the oily mass can, if suitably handled, be ignited when it is gathered together on the shore.

92. The problem of distributing and collecting the enormous amount of straw which would have been required to deal with the quantities of oil released from the *Torrey Canyon* ruled out this method. Supplies of straw were, however, later made available in case oil accumulated on the estuary booms which were erected to protect shell fish grounds.

93. A number of other materials, either in granular or sheet form, were also suggested as scavenging agents. For example, dry granulated peat is used for this purpose by the German river authorities, and the Atomic Energy Research Establishment reported that tanners' waste, if suitably dried, also preferentially absorbs oil. Sawdust is reasonably satisfactory, particularly if treated with a silicone compound to render it water-proof. Of various proprietary materials tested, only a type of vermiculite (exfoliated mica) was found to be really effective. But it is expensive. Granulated polystyrene was also suggested during the period of the *Torrey Canyon* incident. It is particularly good for absorbing oil, but its low density makes it very difficult to spread the material accurately on to a contaminated area.

94. A difficult problem with any granulated scavenging materials is to collect the oil-soaked material from the open sea. Various types of nets or booms are usually recommended, but once again, the scale of the *Torrey Canyon* incident, and the wind and wave conditions in which it took place, ruled out all such methods. The French, however, did try using both sawdust and polythene foam. Collection proved impossible, and the agglomerated particles were eventually deposited on the shores of Brittany.

95. Soon after the *Torrey Canyon* foundered, information was obtained about a costly non-toxic chemical product of American origin which, it is claimed, can be sprayed on floating oil to form a thick gel, which is readily removed by scoops or by skimming. It probably belongs to the class of plastic materials referred to in paragraph 7. A patch of oil is sprayed with a solution of plastic in a volatile solvent. The solvent evaporates, leaving a mat of plastic cobweblike threads over the oil film, with which they form a manoeuvrable material which can then be gathered up, either manually or with the aid of a simple conveyor system, and lifted on board a boat. This particular method has now been tried in the United Kingdom on a pilot-scale. A corresponding suggestion made during the course of the *Torrey Canyon* disaster was to use a rubber latex emulsion instead of the solution of plastic. This could be so prepared that the emulsion would break when it comes into contact with salt water, leaving the latex as a web or film mixed with the oil, which could then be raked up. But although such methods might be suitable in the still water of a harbour, the major problem with both these ideas is that of spraying the mixture over the surface of a rough sea. Time was not available to develop suitable spray nozzles or the best operational technique. The method may, however, be well worth examining further.

96. There is no point in trying to burn weathered oil on the sea after it has lost the more volatile fractions, and by the time it has formed an emulsion containing up to 80 per cent water. Layers of reasonably fresh oil thicker than about one-half inch can, however, be effectively burnt, provided the water content of the water-in-oil emulsion is not greater than about 50 per cent, and provided extra oxygen can be supplied to the mass. The best way to do this appears to be by the use of sodium chlorate 'tiles'. These worked well in preliminary trials with fresh crude oil. They might be made more effective by using a 'deflector plate' which would direct the oxygen-rich flame on to the surface of the oil. Maintaining combustion is difficult, however, both because of heat loss to the sea and because of the quenching action of waves. The possibility of using some form of absorbent material which might maintain combustion by acting as a 'wick' also merits further investigation.

97. If the thickness of patches of oil at sea could be increased by the use of booms, the chances of successful burning would clearly be improved. But there seems to be little prospect for the development of booms which can withstand open sea conditions (see paragraph 104). Even if satisfactory booms could be developed, and an oil thickness of several inches were obtained, it would be preferable to remove this from the water by mechanical or other means rather than to attempt to burn it *in situ*.

6. Keeping Oil off the Beaches

98. From the outset, it seemed highly unlikely that treatment with detergent would prevent all of the *Torrey Canyon* oil from reaching the coast. At their first meeting on 22nd March the Committee of Scientists accordingly considered the possibility of using booms for preventing oil entering harbours, inlets, coves and estuaries, especially where there was any risk to oyster and other shellfish beds, to nature reserves, to other areas of great biological interest, or to yachting amenities. On the following day, 23rd March, the Boom Defence Section of the Marine Services Division, Royal Navy, in conjunction with the Ministry of Agriculture, Fisheries and Food, independently considered types of booms which might be suitable for use in inlets likely to be affected and where fishery interests were involved.

99. On Wednesday, 29th March, the Ministry of Housing and Local Government replaced the temporary arrangements made at the outset by the Ministry of Defence by setting up an Oil-boom Committee at Plymouth to advise local authorities on the choice of booms best suited to local conditions and on means of anchoring them, having regard to what equipment was available. This Committee included a representative of the Hydraulics Research Station which, at the instigation of the Committee of Scientists, had already started experiments to determine the suitability of available booms. Many private firms also provided help.

100. Experience, previous to the *Torrey Canyon* incident, of the containment of oil with floating booms applied mainly to harbours, and it was believed that booms were effective only in relatively calm waters. It had been found that oil passed underneath booms used in containing spillage from anchored tankers if there was any relative movement between the boom and the water surface. Experiments carried out in Portland Harbour to 'tow away' oil trapped in a closed boom had also been unsuccessful. The oil slipped under the boom skirt as soon as it was underway.

TYPES OF BOOM

101. At the time of the first meeting of the Committee of Scientists, 3,000 feet of Aeroprene boom, intended for encircling the *Torrey Canyon*, had already been ordered, and some eight miles of Royal Navy anti-submarine boom netting were also made available. Some of this was later used to protect the Fal estuary at Looe. Subsequently, 21 different types of boom were either tested by the Hydraulics Research Station for their capacity to withstand waves and currents or made available for testing. Others were improvised locally to protect estuaries and harbours. The extent to which these booms could in fact exclude oil could not be studied because of the absence of substantial amounts on the sea in the areas where the tests were carried out.

102. A rapid assessment did however show that the Warne boom, which comprises of a 16 inch diameter foam-filled neoprene flotation cylinder, a 22 inch skirt and weighted lower cylinder, was the most satisfactory commercial

boom which could be produced rapidly and in the quantities estimated as necessary to protect priority sites (see paragraph 143). 10,000 feet were ordered on Thursday, 30th March, and the boom was subjected on 1st April to a severe test at Porthleven, which was chosen because it was one of the few contaminated harbours. Further oil was successfully excluded in spite of a heavy swell (height seven feet). The boom then broke, but the experiment had demonstrated that inlets could be protected from oil if booms of the right design were available at the right time. Suggestions have been made for further improving the performance of the Warne boom, especially the mooring and linkage.

103. An alternative to a floating boom, which was tried at Helford, is a pneumatic barrier formed by the continuous release of compressed air through perforations in a plastic pipe laid on the sea bed. The current so created prevents oil from floating in, but experiments carried out in quiet conditions indicate that the supply of air which would be needed to generate an adequate countercurrent in tidal inlets would be enormous.

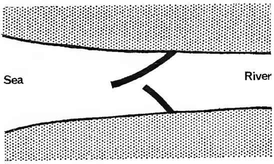
104. The Oil-boom Committee recommended local authorities that none of the booms which were investigated would operate successfully in an off-shore exposed position parallel to open beaches. They concluded, however, that improvised booms can provide initial respite on partially protected beaches. (The booms constructed by the French off the coast of Brittany are reported to have given indifferent results, all eventually being destroyed by tidal currents.) For narrow inlets and harbours, experiments showed that the effectiveness of different types of boom depend on water conditions and rates of tidal flow. Wave heights of greater than 1½-2 feet (smooth wavelets) allow oil to pass over both the Warne-type boom and timber barriers. Tidal currents greater than two knots defeat both the Warne boom and those constructed of oil drums and hessian. It should be noted that costs increase roughly in proportion to the cube of wave height. A boom which would be effective even in slight seas (six to eight foot waves) would therefore be extremely costly.

105. The Oil-boom Committee also recommended that the layout for booms to protect estuaries should be that shown in Figure 1. This results in oil being trapped in shallow water at the banks during the flood tide, where it can be soaked into straw and then removed. Oil that gets into the river can escape during the ebb.

REMOVAL OF OIL COLLECTED BY BOOMS

106. Because the effectiveness of a boom is limited by the accumulation of oil on the 'outside', it is important to remove this with skimmers or in other ways as the amount of oil increases (see paragraphs 83-87). Many ideas were suggested, among which was the craft mentioned earlier (paragraph 84) which sucked oil from the surface and which was known to perform excellently in quiet water. Another was a skimmer of German manufacture capable of dealing with two tons of oil per hour. But this has not yet been tested.

Figure 1. Recommended layout of booms in an estuary



7. Treatment of Oil on the Beaches

107. As mentioned in paragraphs 5 and 6, the Warren Spring Laboratory had enquired, long before the *Torrey Canyon* disaster, into the question of removing oil from polluted beaches and had recommended ways of dealing with small amounts of contamination. The problem posed by the oil deposited by the *Torrey Canyon* was, however, on a totally different scale. As a result of the publicity attending the disaster, scores of proposals about ways of dealing with contaminated beaches and rocky coves were received from the general public, industry and from Government Establishments. Several Government Laboratories, in particular the Warren Spring Laboratory, the Fire Research Station and the Royal Armament Research and Development Establishment, helped in trying out those ideas which seemed worthwhile. The Rocket Propulsion Establishment and the Atomic Weapons Research Establishment also assisted in this work.

108. The methods which were tried fell into three main groups:—(a) dispersing the oil by spraying with emulsifier dissolved in solvent (detergent); (b) burning the oil, either *in situ* or after collecting it in heaps; and (c) mechanical removal of the oil or oil-contaminated sand.

DISPERSAL BY DETERGENT

109. It was fortunate that some five days elapsed before oil from the *Torrey Canyon* arrived on the Cornish coast. This enabled the Ministry of Defence to establish the necessary organisation for the assembly and distribution of supplies and equipment and to issue circulars for the guidance of local authorities. The Ministry of Housing and Local Government took over this organisation on the 24th March. One of the staff of the Warren Spring Laboratory participated in meetings of local authorities and described the proper use of detergent, demonstrations being given to Borough engineers and the Army authorities. The latter, together with the Navy, arranged for the supply and distribution of detergent, and for bulldozers and other equipment to be made available. Unfortunately, there was a considerable shortage of spraying equipment suitable for use in rocky coves which could not be easily reached by wheeled vehicles. As a result, although the detergent was, as a rule, correctly applied, there were many instances of waste and of increased danger to wild life through excessive quantities being poured over contaminated areas.

110. The earlier Warren Spring work had suggested that a volume of detergent equal to some 25 per cent of the total volume of the oil deposited on beaches needed to be applied in order to achieve reasonably effective cleaning, and that an essential final step in the cleaning treatment was liberal hosing down with water, or alternatively that the spraying should be timed so that an incoming tide agitated the oil soon after it was treated with detergent, and so helped its subsequent dispersion into the sea (see paragraph 7). On the whole, this method of dealing with the beaches proved reasonably satisfactory during the early stages when the oil was coming ashore as a relatively thin fluid. In some places, in

particular rocky caves where the oil was deposited above high water mark, the right procedure could not be applied because of the difficulty of transporting suitable pumps. The result was that excessive quantities of detergent were at times used, which both added to the cost of the operation and to the potential dangers to intertidal fauna and flora.

111. After some days most of the oil was being washed up as a heavy water-in-oil emulsion (containing up to 80 per cent water) which, because of its appearance, soon became known as 'chocolate mousse'. Its removal presented great difficulties. The detergent worked satisfactorily only if mixed into the 'mousse' with a good deal of agitation; normal spraying and hosing was not very effective. Specimens of the 'chocolate mousse' were taken to the Warren Spring Laboratory and to the Admiralty Oil Laboratory, and a large number of different mixtures of emulsifiers and emulsion-breaking chemicals were tried. Samples of the most successful were sent to St. Ives for further trials, but none proved entirely satisfactory. Field trials were also made of some of the new emulsifiers which were tested in the laboratory after the ship went aground (see paragraph 81). The conclusion which emerged from this work was that where pollution was heavy, every effort should first be made to remove or burn the oil in order to reduce the amount finally needing treatment with detergent. Such advice was incorporated in a Technical Memorandum issued to all maritime local authorities by the Ministry of Housing and Local Government.

112. It should be noted that when detergent has been used to clean heavily contaminated beaches, some of the emulsion that is formed sinks deeply into the beach. Movement of sand and pebbles also covers up lumps of oily sludge which reappear later as a result of the natural movement of the sands caused by tides. Although much of this buried oil and emulsion was successfully removed by turning the sand over with earth-moving equipment followed by further treatment with detergent (see paragraph 31), it would be useful to have more information about the movement and persistence of these two forms of hidden contamination.

BURNING THE OIL

113. As already noted, from a few days after the wreck had occurred, the main contamination of the beaches was from oil which had already lost its more volatile fractions by weathering, and which had formed a water-in-oil emulsion. This stuff proved extremely difficult to burn, as compared with occasional pools of liquid oil, comparatively free of water, which were easily fired.

114. Many ways of burning the emulsified oil were tried, the test materials either being deposits in rock pools or on the rocks themselves, or masses of the oily mess gathered together in temporary dams constructed of sand or shingle on the beach. The most successful results were obtained when the emulsion was first broken down with detergent, and the released oil then heated and burnt. Breakdown was accomplished by mixing with 5 to 10 per cent of a suitable emulsifier-solvent solution and allowing the mixture to stand for a short period. An addition of 3 per cent of household detergent in aqueous solution also proved effective when the temperature of the oil emulsion was first raised about 35°C by burning gas oil on its surface. The cost of this treatment was, however, high.

115. Attempts were made also to burn deposits of emulsified oil after first soaking up the oil on to various absorbers or 'wicks'. These experiments were only moderately successful. Greater success was obtained when the emulsion had previously been partly broken down by chemical means. It was also found that the addition of a finely divided solid such as powdered pumice would sometimes assist burning.

116. The black emulsified oil in pools in the rocks was easily ignited either by means of a flame-thrower, or by pouring a little flame-thrower fuel into the pool, mixing, and then applying a lighted match. Pools of neat oil burnt almost to completion, but oil burning on water usually generated sufficient steam to extinguish the flame. The fire had then to be restarted after first allowing the water to cool. Pools of brown emulsified oil were extremely difficult to burn by the use of flame-throwing equipment.

117. Where the use of detergent was either undesirable or prohibited, oxy-propane burners of the type used for cleaning masonry proved extremely effective in cleaning rocks, sea walls, etc. A standard four inch burner could clean between 145 and 180 square feet per hour, even though it was somewhat cumbersome to use. While the costs of flame treatment are higher than those of detergent, at first sight it has the advantage of destroying the oil rather than just dispersing it. But the flame tends to cause the surface of the wall or rock to flake, and the clean appearance after flaming is often due to flaking rather than to complete combustion of the oil. Experience suggested that flame-throwers are unsuitable for cleaning rock or stone surfaces because of the slowness of the process and the excessive fuel requirement.

118. Special bricks, made of petroleum coke to which had been added small amounts of fire clay, were also tried as a means of burning the oil sludge. These bricks are normally used for raising the temperature of the air in commercial citrus orchards. They burn for about four hours and produce an intense radiant heat. They proved quite satisfactory in consuming oily sludge, but are far too expensive for general use.

119. Relatively light pollution by semi-solid masses of weathered crude oil can be dealt with by removing the lumps by hand and burning them in improvised incinerators made from oil drums supplied with compressed air. This type of device will also burn fouled seaweed and oiled sand, provided the combustible content is high. A special burner of German manufacture which it is claimed can burn oil emulsions having a water content as high as 50 per cent is commercially available. When the water content is higher, pre-heating is necessary. Because of its very high water content, there is some doubt whether any method is yet available which could deal with the 'chocolate mousse' type of emulsion. There is a clear need for further experimental work on this problem.

PHYSICAL REMOVAL

120. Because wheeled vehicles cannot get down many parts of the rocky Cornish coast which was polluted, it was rarely possible to set about the physical removal of the oil. In Guernsey, however, some 4,000 tons of oil and oil-emulsion were sucked from the coves and beaches by conventional sewage tanker lorries, and then discharged into a quarry. With this method of removal it is necessary to

reduce the amount of sand and pebbles also sucked up because of the vast quantities of material that have to be shifted, particularly where pollution is heavy. The French used mobile steam cleaners on rocky sections of the Brittany coast with apparent success. This method is, of course, conventionally used for cleaning ships' tanks. Again, it could not be easily applied in Cornwall because of the inaccessibility of many rocky coves.

121. As already mentioned (paragraph 112), detergent can carry oil deep below the surface of sandy beaches. Layers of oily sand some 6 to 12 inches below the beach surface were not infrequent. This created a serious problem, partly because of the difficulty of transporting large amounts of sand, and partly because many of the Cornish beaches need all the sand and shingle they have. This difficulty was overcome by using the methods described in paragraph 31. Measurements showed that this method can reduce the amount of oil below the surface to less than one per cent of what it had been before. It was used successfully on a number of beaches.

ABSORBENT BARRIERS

122. Where a beach is threatened by oil pollution, contamination can be minimised by pegging down straw bales or horticultural straw matting at the high water mark, burning the fouled material after the tide recedes, and then replacing with a fresh lot of bales in time for the next high tide. Straw placed at the foot of a wall being cleaned with detergent has also proved very effective in preventing recontamination. It collects a large proportion of the washed-off oil and solvents.

123. The use of powdered solids to absorb or cloak the oil on the beaches, thus rendering the pollution innocuous to beach users, was tried out by the Warren Spring Laboratory during the course of their earlier enquiries. None of these materials proved satisfactory. Unless uneconomically large quantities of the powdered solid were used, it was found that the liquid oil could be squeezed out of the mass when pressure was applied (e.g. by the treated mass being stepped on). Tarry deposits, on the other hand, could not be coated with sufficient material so as to render them innocuous.

8. Effects on Marine Life

124. Since it was apparent that large scale pollution was inevitable, arrangements were made at the start of the disaster to co-ordinate a survey into the effects of oil and detergent on marine fauna, so as to make recommendations on the measures needed to reduce and alleviate damage. The organisations concerned in the work were the Fisheries Laboratories at Lowestoft and Burnham-on-Crouch (Ministry of Agriculture, Fisheries and Food (MAFF)), the Plymouth Laboratory of the Marine Biological Association (grant aided by the Natural Environment Research Council (NERC), and the Nature Conservancy (NERC). The MAFF were concerned with the effects of oil and detergent on fish and shellfish and shared with the Plymouth Laboratory the responsibility for toxicity testing and for shore and offshore surveys. The Nature Conservancy's main task was to consider the possible effects of oil and emulsifiers on important conservation sites in the coastal areas.

EFFECTS OF OIL AND DETERGENTS ON FISH AND SHELLFISH

125. The possible harm to fish and shellfish from oil and detergents has been studied over recent years by MAFF so as to provide a basis for dealing with oil spills. In particular, investigations into the deleterious effects which detergents have on shellfish were undertaken by the MAFF in 1961 and 1962 in collaboration with the Warren Spring Laboratory during the course of the investigation into the best ways of dealing with oil pollution of the foreshores (paragraphs 4-7). These studies included toxicity tests and an examination of the effects on fisheries of sinking oil to the sea bottom. Subsequently, on several occasions when detergents were used in estuaries to disperse oil arising from collisions or oil spills, observations were made to see what effect the oil and the detergent had on shellfish and other organisms.

126. In general, crude oil, when spilled on the sea or washed ashore, very quickly loses its more toxic component fractions and has then no measurable effect on plankton, fish, shellfish or any other forms of marine life with which it may come into contact. It can, however, cause serious tainting of fish which are caught in nets that have been fouled by oil. Shellfish living between tide levels (some oysters, mussels, winkles and cockles) are not often harmed when oil settles on them, but might become unsaleable for many months. Oil which has been emulsified either by detergents or by natural processes can also taint filter feeding shellfish (oysters, mussels, cockles, clams and scallops) by which it is ingested. It can also taint sprats, but it is not fully understood how this comes about. The tainting lasts for only a few weeks.

127. Past toxicity experiments had shown that proprietary brands of emulsifiers kill adult shellfish at concentrations between 10 and 300 ppm (parts of detergent per million parts of water) and other marine invertebrates down to about 1 ppm, depending on the species and duration of exposure. A leaflet issued by the MAFF in 1965 to fishery interests and to coastal local authorities described the effects of oil and detergents on shellfish, and advised that chemical oil-spill removers should not be used in the immediate vicinity of shellfish grounds.

128. In general, it has been found that the more efficient detergents (e.g. BP 1002 which was the main detergent used to deal with the *Torrey Canyon* incident, see Table 1, paragraph 77) are somewhat more toxic to marine life than those which are less efficient. There is, however, a wide difference in the sensitivity of various species of organisms. Thus shrimps are more easily poisoned than either lobsters or cockles (Table 2, paragraph 129).

129. The table below shows the variations in toxicity of five detergents to three different species of shellfish. Obviously the toxicity of a poison depends on the amount that is ingested, which in this case had been determined by placing a number of each species of shellfish in several different vessels containing fresh sea water to each of which had been added a different amount of detergent. The number of animals dead at the end of various periods of time was counted, and from the results the contamination (dose) of detergent in sea water which would just kill half the animals if they were constantly exposed for one hour, eight hours, and forty-eight hours was calculated. It should be remembered that the more toxic solutions are those which require a *lower* dose to have an effect. Furthermore, as can be seen, since the exposure to the poison is continuous, the longer the period of exposure the smaller the lethal dose.

TABLE 2

		Concentration of detergent in sea water which kills half of the animals exposed (in parts per million*)		
		Duration of Treatment		
Detergent	Species	1 hour	8 hours	48 hours
BP 1002	Cockle	3,300	250	81
	Shrimp	32	3	6
	Lobster	200	20	45
Polyclens	Cockle	10,500	800	70
	Shrimp	50	12	16
Gamlen	Cockle	12,000	890	16
	Shrimp	90	7	9
Cleansol	Cockle			19
Essolvene	Cockle			25

* 1 part per million is equivalent to 1 fluid ounce in 6,250 gallons (or approximately 1 drop (0.1 ml or 2 minims) in 22 gallons).

OBSERVATIONS ON COMMERCIAL FISHERIES

130. The following fish and shellfish in south-west Britain were potentially under threat from pollution as a result of the *Torrey Canyon* disaster:

(a) *bottom fish* (plaice, sole, brill, cod, pollock, ray, etc.) caught by trawls on many grounds in the western English Channel and Irish Sea to within a mile of the coastline;

(b) *midwater fish* (mackerel, pilchard, sprat) caught by line or drift net along, and off, the Cornish coast;

(c) *crustacean shellfish* (lobsters, crabs, crawfish) caught by pots; crawfish occur in the deeper rocky areas, but crabs and lobsters extend from the deeper water to the shallow inshore grounds all round Cornwall and all along the south and west coasts of England and Wales; and

(d) *molluscan shellfish* (oysters, mussels, scallops, etc.); very important oyster grounds are present in the Helford, Porthcuel and Fal estuaries, but apart from these the nearest estuarine molluscan fisheries of importance are at Teignmouth (mussels), Exmouth (mussels) and Poole Harbour (oysters, cockles and winkles); large stocks of scallops occur off Plymouth, but these are in deeper water.

131. On the advice of their own experts, the Ministry of Agriculture, Fisheries and Food straightaway suggested that the use of detergent in estuaries, more particularly in the Helford, Porthcuel and Fal estuaries should be banned, but accepted the extensive use of detergent on the open sea and on the open coast.

132. The Fisheries Inspectorate of the Ministry of Agriculture, Fisheries and Food, with offices in Plymouth and Newlyn, were immediately called into action and organised the chartering of the fishing vessels which were used in spraying detergent at sea. Immediate and accurate information about the effects of oil and detergent on commercial fisheries was collected by MAFF officers and other field workers, who were also able to examine the spate of rumours that started to flow in. Use was made of the Marine Biological Association's vessel RV 'Sarsia' and other vessels chartered specially by MAFF for the purpose. Several biologists, including some proficient in underwater swimming, from both governmental and non-governmental research establishments, were engaged in this work, which was co-ordinated by MAFF and the Plymouth Laboratory of the Marine Biological Association. They surveyed trawl fisheries as well as Cornish lobster and crab fisheries, and also studied the critical inshore zone, 60 feet wide out from low water mark, wherever there had been much oil or spraying. This work was directed by a senior MAFF fishery biologist stationed at Plymouth, in co-operation with the Plymouth laboratory of the Marine Biological Association (MBA) and in close liaison with the Fisheries Inspectorate at Newlyn. The MAFF Plymouth office is situated in the MBA laboratory which was also used as the local headquarters of the Nature Conservancy, thus further facilitating the interchange of information on all matters affecting fisheries and marine life.

133. Observations by divers along the coast showed that a few conger eels, small dabs, flounders and eel elvers were being killed close inshore, but the results of trawling yielded no evidence of damage to commercial fisheries. Commercial trawling and line fishing were resumed very shortly after these negative findings were reported and when the oil had cleared from the fishing grounds. Fortunately oil did not reach any molluscan fisheries.

134. During April and May observations by divers and on the beaches showed that several hundreds of crabs, mostly small ones, and a few lobsters had been killed in the areas where the detergents had been used in large quantities (e.g. see paragraph 148). The lobster fishing season started in April, and inshore

catches appeared to have been somewhat below average in some areas, but offshore catches have been above. It is clearly impossible to decide whether any significance can be attached to these observations. There was no evidence that crawfish were harmed.

135. Some lobsters which had been held in store pots not far from beaches which had been heavily treated with detergent were found to be tainted, as were a few others which were caught within about a mile of these areas. The tainting affected chiefly the digestive and reproductive organs, but in extreme cases had also made the white meat unpalatable.

136. While only affecting a small proportion of the catch, tainting led to some sales resistance. Tainted lobsters lose their objectionable flavour after storage in clear seawater, but the cleansing process may require up to 14 days.

137. As was expected, marine fauna and flora in the intertidal zone of the affected areas and just below low tidal level suffered severely wherever large amounts of detergent had been applied. These effects are described in more detail below (paragraphs 147-152).

138. The records of at least one full fishing season will have to be studied before it can be known for certain that the damage to lobsters and crabs has been as limited as now appears. The available information merely suggests that it is only in conditions such as are found in Cornish waters that detergents can be applied on the scale used after the grounding of the *Torrey Canyon* without causing harm to marine fish and with negligible loss of commercially important shellfish. There are few areas around Britain with correspondingly favourable topographic and other environmental characteristics where oil and detergent would have done so little damage to fisheries.

9. Effects on other Wild Life

139. The oil released by the *Torrey Canyon* caused widespread damage to intertidal marine plant and animal life, and was responsible for the destruction of significant numbers of seabirds over a wide area. The damage to intertidal plant and animal life was aggravated by the use of detergents. Back shore dune and cliff plants suffered from bulldozing and trampling by decontamination workers and from the spillage of detergent.

140. As pointed out in paragraph 24, the coincidence of the arrival of the bulk of the oil with the high spring tides of 26th March, backed by gale force winds, carried the oil to the highest possible point of the intertidal zone on exposed coasts (on the West Lizard the cliffs were covered to a height of 30 feet). In all 140 miles of the Cornish coastline were affected, more severely on the north than the south. Many areas of scenic beauty (including 40 holiday beaches) and others of high scientific interest were affected.

MEASURES TAKEN FOR THE CONSERVATION OF COASTAL HABITATS

141. As soon as the scale of the disaster was appreciated, and before any oil had hit the shore, action was taken to protect coastal habitats of importance to conservation. The Nature Conservancy (Natural Environment Research Council (NERC)) was formally responsible for co-ordinating this work, in which many naturalists' organisations participated. A temporary Conservancy office was established in the laboratory of the Marine Biological Association in Plymouth which, as has already been mentioned, is grant aided by the NERC.

142. The Conservancy's main task was to consider the possible effects of both oil and emulsifiers on sites of special scientific interest scheduled under Section 23 of the National Parks Access to the Countryside Act, 1949, and to decide what might be done to prevent or minimise the damage to these and other important coastal areas, including some managed as nature reserves by voluntary bodies. The Conservancy also made extensive preparations to anticipate the threat of pollution along a stretch of coastline extending as far as the Thames Estuary. The Conservancy's South Wales and East Anglia Regional offices were also alerted.

143. A list of 26 sites, many of them estuaries, which were of great importance to conservation and fisheries, was prepared in conjunction with the Ministry of Agriculture, Fisheries and Food. This schedule, together with a supplementary list of coastal sites of scientific importance because of their plant and animal communities, was distributed to the Government Regional Headquarters and local authorities together with a warning of the dangers to wild life through the excessive use of detergent. Local authorities were also advised directly that the use of detergent should be confined to sandy or gravelly beaches of greatest aesthetic and recreational importance, and that wherever possible nature reserves, sites of special scientific interest, and other areas of high biological value, should not be treated. The importance of protecting estuaries both from

oil and detergent was emphasised, and the provision of booms in suitable places encouraged. As a result, detergent was not used in the Hayle Estuary.

144. Despite these recommendations, amenity considerations were understandably given highest priority, and there was widespread damage to the fauna and flora either from the use of detergent, or by oil which had been emulsified by detergent.

SURVEYS OF MARINE AND COASTAL SITES

145. The extent of pollution at conservation sites was recorded daily during the period of emergency. All scheduled sites affected by oil have since been visited regularly, and reports compiled about the visible effects on vegetation and fauna. The Marine Biological Association has closely surveyed some shore areas to determine the effects on marine organisms, and has continued to study the rates of recolonisation of oiled and detergent-treated rocks. A detailed report of this work is shortly to be published.

146. The Nature Conservancy, together with the Royal Society for the Protection of Birds (RSPB), The British Trust for Ornithology and other voluntary naturalists' organisations, co-ordinated the recording of the sea bird casualities.

THE EFFECT OF OIL AND DETERGENT ON COASTAL HABITATS AND MARINE LIFE

147. The West Lizard and Penhale Sands were the only top priority sites for wild life conservation which were contaminated, and then only moderately. Seventeen second priority sites on the coastline were affected by oil, the foreshores of 12 being fairly heavily contaminated. Widespread and considerable harm was done to marine plant and animal life between the tide marks on rocky shores, and scattered and generally less severe damage to vegetation on salt marshes.

148. Sennen Cove was an area which suffered more than most. Up to three feet of oil was reported in rock pools, and detergent was very heavily used (over 20,000 gallons per day), while the beach was subsequently bulldozed (see paragraphs 31 and 121). A number of dead fish and invertebrates (sea anemones, limpets, barnacles, etc.) were picked up on the rocky part of the shore; some polychaete worms (ragworms and lugworms) were still alive. With the exception of some resistant species, all the marine algae (seaweeds, etc.) had been destroyed. On the other hand, marine life was relatively little affected in many places round the coast where detergent had been used sparingly, or where tidal currents had kept detergent streams away from rocks. In such places the seaweed was extensive and healthy; periwinkles, top shells and limpets were present in large numbers and appeared to have suffered no casualties.

149. It has since been reported that an investigation of seaweed in the polluted area carried out during the summer (1967), has shown that kelp forests below low water mark were quite unharmed, even where detergent had been heavily applied. On many Cornish beaches (e.g. Sennen Cove), where detergent had killed off limpets which normally 'graze' on the green seaweed which covers rocks, an uncontrolled spread of seaweed has taken place. On other heavily treated

beaches, the rarer species of seaweed have been reduced in quantity, but not entirely eliminated.

150. Salt marshes were, in general, not damaged. Those of the Hayle Estuary, particularly the zones of reed in the upper estuary and red fescue and sea-beet in the mid-estuary, were completely covered with a thin, black layer of oil. The marsh areas were only affected by an extremely thin film of oil, and the colonising plant species remained green. Mudflats below this level retained living ragworms and were hardly affected at all. On the Gunnel Marsh, contamination was similar, but the oil reached an even higher level and affected the scrub of blackthorn, hawthorn and oak at the limits of the highest tides. The main marsh was very lightly contaminated with oil and the plants remained green. Detergents were not applied either to Hayle or Gunnel Marsh, but the Hayle Estuary may have been contaminated to some degree because of the intensive treatment of the beaches near its mouth.

151. Extensive and thick oil deposits occurred on many sandy shores, but were generally patchy in nature. In some places, subsequent spraying, trampling and bulldozing spread the oil, so that the whole sandy shore became lightly polluted to a depth of about one foot. Direct contamination of sand dunes nearest to the sea occurred only as a result of oil splash. Most of the serious damage to plant communities on dunes adjoining beaches and at the rear of the beaches (strandline flora) occurred through the to-and-fro movement of decontamination workers, or by spillage of detergent. It is probable that some species of strandline flora will be reduced and, for the time being even eliminated in certain coves.

152. Some local plants growing above tide marks, such as ferns and lichens, were heavily contaminated by thick oil splash on many of the more exposed west-facing cliffs of the rocky Cornish coast. Damage, mainly due to the spill of detergent, to cliff-top grasslands and grass heaths was observed, and some patches of cliff-top vegetation up to 200 square yards in extent were killed. Some undercliff vegetation was also killed by detergent poured from cliff tops on to inaccessible beaches. Since many of the rare plants on the West Lizard are found extremely locally on cliff edges and undercliffs, their survival may have been menaced. Fortunately many parts of the coast were unaffected either by oil or detergent, and it is possible that recolonisation will occur more quickly than seemed possible at first.

MEASURES TAKEN TO RESCUE AND CARE FOR OILED SEA-BIRDS

153. Oil pollution has been a hazard to many species of sea birds for at least 50 years, and the yearly toll round the British coast is reliably believed to be some thousands of birds. The marked decline in auks (guillemots and razorbills) breeding on the southern British coasts over the past 30 years is considered by many ornithologists to be due primarily to oil pollution.

154. The Nature Conservancy and the Royal Society for the Protection of Birds (RSPB) were jointly responsible for co-ordinating the work of rescue and treatment of oiled sea-birds after the *Torrey Canyon* grounded. The work of collecting oiled birds and the establishment of cleansing and rehabilitation centres were undertaken by the Royal Society for the Prevention of Cruelty to Animals (RSPCA) in association with the RSPB and other voluntary organisations. The Nature Conservancy helped by giving advice and by providing an information

service to facilitate co-ordination of the voluntary effort. It also gave practical assistance at various centres. Unfortunately the facilities for cleansing birds had often to be improvised to meet the emergency, while a large number of inexperienced voluntary helpers could not be given full guidance because of the shortage of trained personnel.

THE DEGREE OF OIL CONTAMINATION IN SEA-BIRDS

155. The totals of oiled sea-birds brought in to cleansing and reception stations after the *Torrey Canyon* disaster were: Guillemots, 6,355; Razorbills, 1,384; Shags, 41; Puffins, 42; Great Northern Divers, 18; other species, 9. These figures do not, of course, provide any indication of the number of birds which were dead before they were washed ashore or which died at sea and were not recovered. Moreover, some live birds were picked up and cared for by private individuals, and a considerable number came ashore on inaccessible beaches. Taking all these factors into account, it has been estimated that the total casualties along the English coast were about 20,000 guillemots and 5,000 razorbills.

156. The latest data indicate that the present breeding population of guillemots between the Isle of Wight and Cardigan Bay amounts to approximately 20,000 birds, and that of razorbills 14,000. Guillemot casualties resulting from the *Torrey Canyon* may thus have been as numerous as the whole of this particular guillemot breeding population, and razorbill casualties equal to a third of the corresponding breeding stock. Preliminary observations seem to indicate that there have also been marked reductions in the breeding populations of herring gulls and shags.

157. Recoveries of ringed birds since the disaster indicate that colonies as far north as Rathlin Island, Antrim, may have been significantly affected. Among other species, the small populations of puffins in the South West may have suffered significantly despite the small number of casualities observed. The losses among other species appear to be very slight, and will very likely be rapidly made good. It must be emphasised that all these estimates are highly provisional. The true impact of the *Torrey Canyon* will not be known until reliable colony counts of several different species in different localities are obtained.

CLEANSING AND REHABILITATION

158. Within a few days of the grounding of the *Torrey Canyon*, most of the accessible beaches in Cornwall were being regularly patrolled for oiled seabirds. When found, they were taken to RSPCA cleansing stations, where several kinds of treatments were tested. Details about their relative success will be published after the results have been completely assessed. After cleansing, the survivors were sent by road to rehabilitation centres.

159. In spite of the enormous efforts of those who helped, the results were very disappointing. Of the 7,849 birds recorded as having been brought to cleansing stations, only 450 were still alive by mid-April, and subsequent mortality further reduced this number so that less than one per cent of the birds treated are likely to be returned to the sea. Thus only a minute fraction of the auks which were affected by pollution from the *Torrey Canyon* are likely to regain a place in the communities from which they came.

SEALS

160. There were few reports of seals affected by oil, although many of their breeding caves were reported to be contaminated. It has been proposed that a count of the breeding population of grey seals in the Isles of Scilly and in Cornwall should be made during 1967, and that surveys of all breeding caves should be undertaken in the early summer of 1968.

THE OIL POLLUTION IN BRITTANY

161. Two officers of the Natural Environment Research Council spent five days (24th-28th April, 1967) investigating the pollution of the coasts of Brittany. Their general conclusion was that contamination was heavier and more continuous than in many Cornish areas, and that it was mainly in the form of 'chocolate mousse' which was hence not easily removed by treatment with detergent (see paragraph 111). The avoidance of the use of detergent in Brittany may have helped to reduce damage to flora and fauna, and it was noted that even in the worst polluted stretches of rocky coast there were patches of surviving vegetation and fauna from which recolonisation could occur. Nevertheless, it seems probable that the difficulty of removing contamination may have resulted in greater damage to the Breton oyster industry than was experienced in Cornwall, and it is doubtful whether the discolouration of miles of rocks will disappear for very many years. An account of these observations will be included in the Marine Biological Association's report (see paragraph 145).

10. Conclusion and Recommendations

162. The *Torrey Canyon* disaster is, to all intents and purposes, a thing of the past. Having polluted the French coast at the beginning of April, the last large patches of oil from the tanker were disposed of by the French Navy in early June. The summer brought few complaints either from holiday-makers or fishermen, or if they were made, they were so muted as to have attracted no notice in the national press. There is hardly any memory of the public anxiety which prevailed during the period of crisis in the latter part of March and early part of April.

163. The disaster was in every respect as unprecedented as it was sudden. Its scale, as well as the circumstances by which it was surrounded, were unique. Yet in some respects we were lucky to have got off as lightly as we did. If the ship had grounded and then broken up in some other coastal area, for example in the shallow parts of the North or Irish seas, the problems raised and the damage caused could have been on a vastly greater scale than was actually experienced. A combination of shallow water, of less favourable tidal currents, and a greater degree of coastal confinement, would have increased the difficulties of dispersing the oil as well as the extent of pollution of the coastline and the danger to fisheries and wild life. Had—to take the worst possible case—the tanker been badly damaged through collision in a confined area, such as the Thames Estuary, burning the cargo would almost certainly have been ruled out because of the hazard of spreading fire or of unacceptable pollution, and, in any case, it is unlikely that bombing of such a tanker in order to ignite the oil would have been allowed. Although salvage might have had a greater chance of success in such circumstances, the time it might have taken could have led to an unacceptable degree of pollution if the ship had been spilling oil. It is a sobering thought that each thousand tons of crude oil washed on to a beach 30 feet wide could form a layer half-an-inch thick for 20 miles. A thousand tons of oil discharged in a less favourable area than the Seven Stones reef might thus have had consequences at least as serious as those which followed the spillage of the 95,000 tons or so from the *Torrey Canyon*.

164. When the disaster occurred, the need for immediate remedial action was urgent. Correspondingly, the technical and scientific problems which sprang to the fore could barely be formulated properly in the time available, leave alone fully answered. The situation was changing all the time, and was seldom the same in any two places. Improvisation was the order of the day. But much of permanent value was nonetheless learnt from the disaster, and since the menace of further accident is very real indeed it is essential that enquiries which were started when interest in the wreck was at its height, and which had as their aim the improvement of measures for dealing with the whole problem of oil pollution, continue to be pursued with vigour.

165. We were not asked to propose ways by which the risks of tanker accidents could be reduced, any more than, as a Committee of Scientists, it was our business to consider how legal sanctions against oil pollution could be made more

effective than they appear to be, or how the administrative control of the measures taken to alleviate disasters once they have occurred should be best arranged. Obviously, the more effective all these things become the simpler would be the scientific and technical problems that are involved in dealing with the menace of oil pollution. But there is a general point we can usefully make in this connection, since it is one of the basic lessons that can be derived from the *Torrey Canyon* disaster.

166. Practically every issue on which decisions for action had to be taken during the period of crisis was at least partly of a scientific or technical nature. If another disaster on a corresponding scale occurs, we would, therefore, suggest, as was done in our own case—that a team of scientists should be immediately appointed to co-ordinate scientific advice. Their particular disciplines would be of lesser importance than their ability to act quickly and to deal dispassionately and objectively with new problems. They should be at least generally conversant with technical developments relevant to the kind of problems likely to be encountered, and aware of the scientific institutions and individuals who could provide specialised information or undertake specialist work. They should be given—as we were—authority to call, as and when required, for scientific and technical help from whatever quarters for the direction and rapid execution of any action decided upon.

167. We turn now to the more precise matters which we have learnt from the disaster and where, in certain cases, we recommend that further enquiries be carried out. The first relates to the question of salvage. Given an accident which immobilises a tanker and in which spillage occurs, there can be no dispute about the general proposition that every effort should first be bent to salvaging the ship and disposing of its oil in such a way as to prevent further pollution. This was the course to which the authorities correctly directed their attention immediately after the *Torrey Canyon* drove on to the reef. But as it turned out, the weather put an end to the salvage effort before it had yielded any dividend. After the oil was disposed of by bombing, there was much public criticism that the Government should straightaway have ordered the burning of the oil in the ship, instead of permitting salvage operations to proceed. As already noted, the Committee of Scientists and the Naval salvage expert took a less optimistic view of success than did the commercial salvors. Nevertheless it was recognised that successful salvage would be the best means of preventing further pollution, and the fact that salvage was not in the end possible does not mean that it was wrong to try. In any similar case a decision to attempt salvage should, of course, always be conditional on some useful progress being made within a period of time, which should be defined in the light of the weather conditions, the likely cost of dealing with potentially increasing pollution and the salvage value of the prize.

168. Unless the chances of successful salvage seemed almost certain in any disaster corresponding to the *Torrey Canyon*, it is clear that immediate consideration should be directed to all the aspects of the problem which we had to take into account, as set out in paragraph 21, even if this were done only in the framework of contingency plans.

169. Except in sheltered waters where waves exceeding two to three feet can be ruled out, it is pointless, in our view, to consider containing spilled oil by means

of floating booms of the kind now available, nor in our view are any of the new ideas for such booms, as were put to us at the time of the stranding, likely to work on the open seas. Given a tanker accident, the most urgent matters for consideration are, first, disposing of the oil in the stranded ship, and, second, treating the oil on the surface of the sea. The particular lesson of the *Torrey Canyon* disaster is that if all other methods of oil recovery prove impracticable when a ship cannot be salvaged, and provided that the location of the wreck permits, the cargo can be burnt, if necessary being set on fire by bombing. In theory the best way to dispose of the cargo is, of course, to pump it out into receiving vessels, as discussed in paragraphs 46-50. If this proves impracticable, the next best course is to fire the oil after the tanks have been vented by properly placed charges designed for the purpose (paragraph 60).

170. A suggestion was made to us that tankers should be fitted with devices which make it possible to gel the oil *in situ*, given that in the case of collision or stranding it proved too difficult or altogether impractical to pump out the oil. While this idea is good in theory, we understand that its implementation presents serious difficulties, in particular because considerable power would be required to mix the gelling agent with the oil in the tanks.

171. The *Torrey Canyon* incident revealed a painful ignorance about a number of matters which should now be urgently enquired into if oil is to be more rapidly, safely and efficiently disposed of in any future incident. We hope that it will be possible to arrange for much of the research work involved to be done on an international collaborative basis, perhaps co-ordinated through the Inter-Governmental Maritime Consultative Organisation.

172. The history and methods of salvage operations need to be collated. There should be a co-ordinated effort to assemble information from all sources about the availability and adequacy of general salvage equipment and, in particular, of equipment and methods to assist stranded tankers. Where inadequacies are revealed, research and design studies should be undertaken with the aim of overcoming them. An assessment should also be made regarding the probable nature and frequency of future incidents of large-scale oil pollution of our coastline, so that the necessary scale of future effort to meet such threats can be more readily determined.

173. In order to ensure the rapid removal of oil (or any other hazardous cargo) from a stranded cargo vessel to a lightening ship, to aid in the salvaging operation, a study should be made of substantial and portable fendering, of mooring techniques and of the best means of connecting floating hoses. Work should also be done on the design and construction of high-capacity (say, 500 ton per hour), petroleum-safe, submersible, portable pumping equipment and ancillaries for use on a damaged vessel.

174. Furthermore, while much has been learnt about the disposal of oil by burning, we would recommend that further enquiries into this problem, particularly the problem of firing oil *in situ* in a wrecked tanker, should be pressed. Where the location of a wreck does not permit burning of the oil (e.g. in estuaries or harbours), it may be possible, as already noted, to gel the oil or to use mechanical methods to slow down or prevent spillage from the tanker. While such methods are unlikely to be practicable in most circumstances, they should nonetheless be borne in mind (see paragraph 178 below).

175. Our assessment of the results of the action which was taken to deal with oil spilt on the open sea leads to the conclusion that, given the accident were to recur as and when it happened, we would again advocate spraying with detergent unless the decision had been taken to fire the ship, in which case we would recommend setting fire to the oil as it spilt into the sea and before its volatile fractions had evaporated (see paragraph 96). There is however a need for more research both on the development of more effective detergents for use at sea (see also paragraph 182) and on the best methods for igniting and maintaining combustion of freshly spilled oil.

176. We are glad to note that research is being continued by the National Institute of Oceanography (part of NERC) and by other interested bodies into the movement of oil slicks on the sea (paragraph 71). These studies should help enormously in predicting the possible severity of pollution, and in helping to direct remedial operations at sea, given any future incident. We presume that these endeavours will continue to receive active support. At the moment, information is lacking about the chemical processes which are involved in the weathering of different types of crude oil. A study should therefore be undertaken of the quantitative effects of natural environmental forces in dispersing and destroying oils of differing physical and chemical properties, and of the factors determining the formation and stability of different types of oil-water emulsions.

177. Other enquiries should be directed to the disposal of the oil by sinking with powdered high-density materials. To this end a study should be made of the most effective particle size and methods of distribution. The conditions under which biological destruction of the sunken oil takes place either naturally, or by the addition of oil-destroying micro-organisms to the sinking agent, should also be the subject of enquiry.

178. The possibility of developing cheap, effective, floating, oil-absorbent material and methods for collecting the oil-soaked material in the open sea also needs to be examined. Since present methods for gelling oil on the sea are both very expensive and of limited value, research might continue into the formulation of cheaper gelling agents effective in low concentrations for the treatment of floating oil in estuaries and harbours.

179. In parallel with these enquiries, consideration should be given to the provision of ships or other craft specially equipped to spray detergent and to ensure it is adequately mixed with the oil. It appears possible that suitable coastal tankers could be economically adapted for this task.

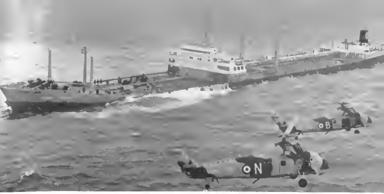
180. Experience has shown that it is extremely doubtful whether mechanical removal of oil from the open sea by skimming or by suction is a practical proposition. Nor does it seem likely that booms can be developed at a sufficiently low cost for anchorage offshore to protect exposed beaches. However, although the lessons we learnt during the *Torrey Canyon* incident were not sufficient for us to conclude with certainty that booms will provide the necessary protection of harbours and inlets without also being prohibitively costly, it would appear useful to carry out further work aimed at devising a sufficiently cheap and effective boom for use at such sites. We feel that any research which might be continued to see whether booms could be constructed for effective use on the open sea should only be carried out as an extension to this.

181. Most of the criticisms which were levelled at the action taken by the authorities during the course of the incident referred to the excessive use of detergents on the beaches and other parts of the coastline and the damage this caused to flora and fauna. We are in no doubt that wherever possible mechanical means should be used for removing oil from beaches before resorting to treatment with detergents. This was made clear both to local authorities and the Services in circulars and directives issued on our advice by the Ministry of Housing and Local Government while the cleaning-up operation was in progress. We recommend that further research be carried out designed to improve mechanical methods for the removal of oil from beaches, and its disposal by burning. These studies might be extended to an examination of clearing oil-pollution from rock surfaces by burning or by steam cleaning, for use in cases where such action is considered essential on beaches of high amenity value.

182. It must be recognised, however, that there are difficulties in many areas in getting even adequate spraying equipment, let alone earth-moving or steam cleaning machinery, onto beaches and rocky coves. In such cases it appears likely that, where gross re-pollution seems probable, the areas must be cleaned by the use of detergents in spite of the damage this might cause to fish and other wild life. We recommend therefore that further research be carried out on the toxicity of the various constituents of detergents with a view to developing mixtures which combine the maximum effectiveness of emulsifiers with minimum toxicity and persistence.

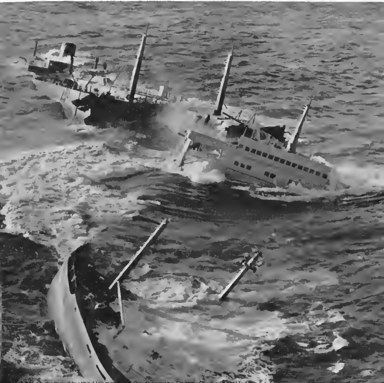
183. Both the incident and its aftermath have pointed to the need for further research on the effect of oil and detergent on fish and other marine life, seabirds and coastal vegetation. Not only are continued records of the changes in population of various species required, but we also need controlled experiments on the ecological effects of all methods of oil removal. The effect of oil on seabirds was particularly unfortunate, and more research is required into methods on cleaning and rehabilitation of oiled birds.

Printed in England for Her Majesty's Stationery Office by McCorquodale & Co. Ltd., London
HM 2152 Dd 137233 K40 12/67 McC. 3309



1 The Torrey Canyon stranded on the Seven Stones rocks. *Photo: Crown Copyright*

2 The Torrey Canyon after breaking into three sections. *Photo: Crown Copyright*



3

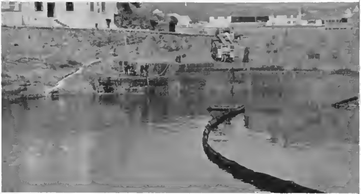
4

3 The Torrey Canyon, with smoke billowing from burning oil, after bombing by R.N. aircraft.

4 The wreck of the Torrey Canyon, with oil burning on the sea surface, after bombing by R.N. and R.A.F. aircraft.
Photo: Crown Copyright

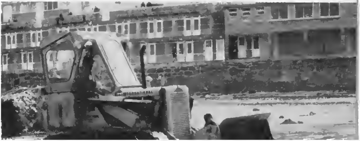
5 Porthleven Harbour, 7 April, 1967. The floating boom which had been used in an attempt to keep oil out of the harbour.
A fire tender is seen pumping water for hosing operations within the harbour.
Photo: F. J. Warren, Copyright

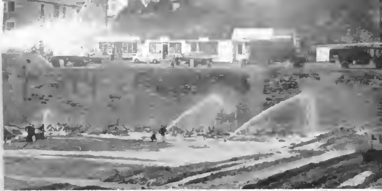
6 Porthmeor Beach, St. Ives, 28 March, 1967. Bulldozing oiled sand.
The beach is covered with a sheet of shining oil.
Photo: R. Swinten, Copyright



5

6





7 Porthleven Harbour, 28 April, 1967. Bulldozing the bed of the harbour at low tide and spraying the oil-covered walls with detergent. *Photo: P. E. Gibbs, Copyright*

8 Porthmeor Beach, St. Ives. Army personnel moving oil-soaked sand.
Photo: Crown Copyright